MAY 24 1930

THE JUNE SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

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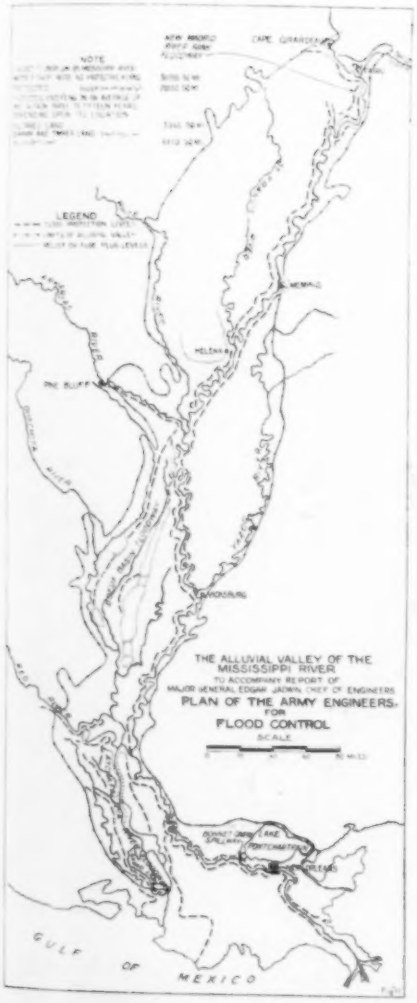
THE SCIENTIFIC MONTHLY

JUNE, 1930

FLOOD CONTROL WORK ON THE MISSISSIPPI

By Major General LYTLE BROWN

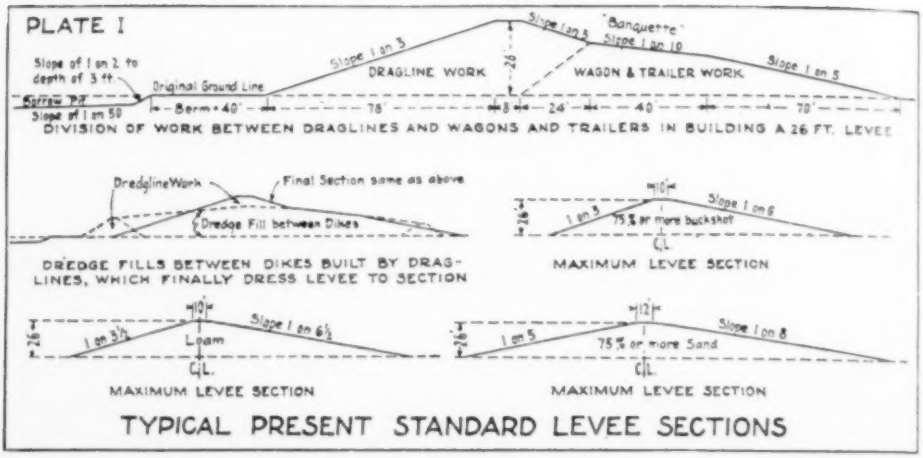
CHIEF OF ENGINEERS, U. S. ARMY



When the term Mississippi Valley is used it generally means the lands bordering the Mississippi River which are naturally subject to overflow by the highwaters of the river. These particular lands consist of alluvial soil which has been deposited by overflows throughout the ages. The real highwaters of the river always occur in the spring between February and June. They vary in height from forty feet above low-water stage to sixty or seventy feet above low-water stage. Since the banks of the river are about forty feet above low water the waters generally rise during each spring high enough to overflow the lands. However, there are some seasons in which the waters rise barely enough to overflow the banks of the river. And of course the extreme highwaters are not very frequent.

For over a hundred years the people of the Mississippi Valley have been protecting their lands from overflows by means of levees or earthen dams. At this time the levees are from twenty to twenty-five feet high above the natural bank level so that all but the major highwaters are restrained between the levees and kept off the lands through which the river flows.

When levees were first used they were merely small mounds of earth thrown up around individual plantations. Gradually these mounds were made higher and



higher. Plantations began to combine their protection levees, and these grew into a system of levee districts which were chartered by the several states. These levee districts are political subdivisions that can raise taxes and expend funds. They do not always happen to fit in with the physical situations with respect to flood control. However, in such cases they have frequently united in the expenditure of funds for their mutual protection. Now the United States is bearing almost all the expense of flood control in the lower Mississippi Valley.

The alluvial valley of the lower Mississippi is composed of five major basins, which are the logical parts to consider

METHOD OF TREATING SAND BOILS

BETWEEN BATON ROUGE AND NEW ORLEANS, LOUISIANA, ON THE MISSISSIPPI RIVER.

from a flood protection point of view. In each of these basins is a major water course which can serve for local drainage. There must be outlets for local drainage, and each basin has such an outlet either into the Mississippi itself or into the Gulf of Mexico. These basins are the St. Francis Basin in Missouri and Arkansas, the Yazoo Basin in Mississippi, the Tensas Basin in Arkansas and Louisiana, the Atchafalaya Basin in Louisiana and the Pontchartrain Basin in Louisiana.

TREATMENT OF SAND BOILS

NEAR BORDELONVILLE, LOUISIANA, ON BAYOU DES GLAISES.

The alluvial lands in Missouri, Arkansas and Mississippi are used mostly for cotton. In Louisiana sugar as well as cotton is grown. It is worthy of note that the fertile soil of the alluvial valley produces a long staple cotton which is superior to the cotton grown on hill lands and brings a higher price. The yield of these lands is also greater per acre than that of hill lands. The fact that it is possible to raise as much as two bales of superior cotton to the acre on some of these lands is sufficient explanation of the efforts made to reclaim and protect them. Naturally the production of wealth by fertile lands brings about the establishment of prosperous towns and even wealthy cities within the overflow territory. These serve as a major incentive toward protection against flood waters.

Nature has brought about the alluvial valley by successive deposits from overflows. When overflows were not prevented, each year saw an addition to the land elevation. The spilling of water out of the river channel caused greater deposits close to the river channel than at a distance from the river because where the current was first checked the deposit was greater. In this way the river banks grew higher than the general elevation of the valley. When levees were located they were naturally placed on the highest ground, and this in gen-

RINGS OF SAND BAGS

AROUND SAND BOILS NEAR NEW ROADS, LOUISIANA, DURING FLOOD FIGHT.

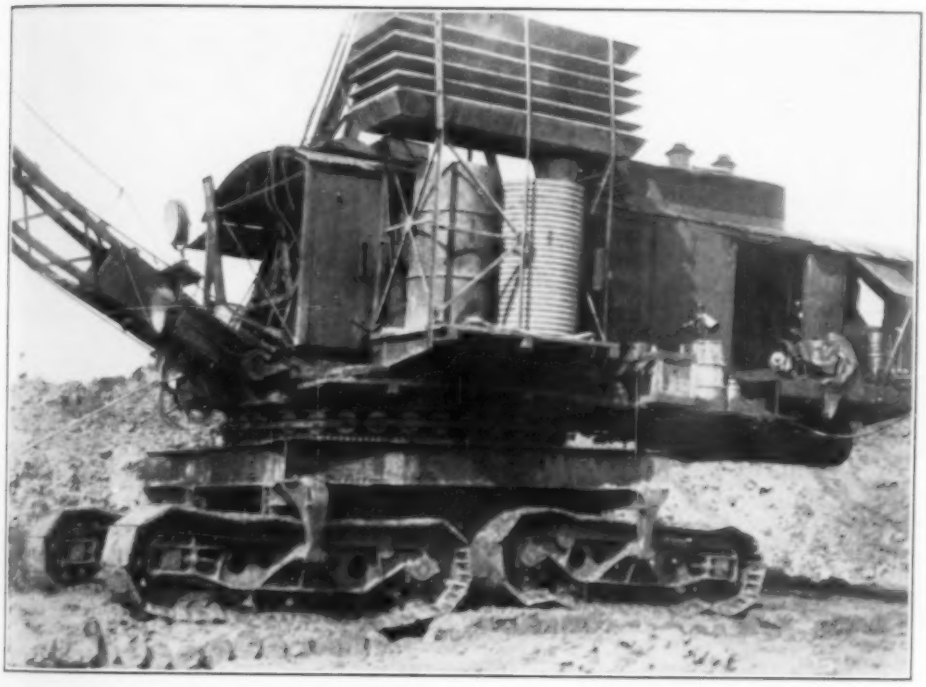
DUMP WAGON

OF SEVEN-YARD CAPACITY, USED IN BUILDING LEVEE

eral is near to the channel. This has an advantage since all the local drainage flows away from the levee toward interior tributaries which ultimately empty into the main river or into the gulf.

The deposit from overflow water is fine silt and is very fertile. After each overflow the land usually produces much better crops than it has produced when not subjected to overflow and silt deposit. The Mississippi Valley is so fertile that in general it has not suffered from lack of productive capacity. This is the case partly because no portion of it has up to this time been entirely protected from overflows for long periods of time. However, in recent years some of the lands have begun to show deterioration because they have been protected for a long time. For example, in the upper Yazoo Basin protection has not failed for forty or fifty years and the land is becoming reduced in fertility. Now that the greater part of the valley is to be given total protection this question of the wearing out of agricultural lands may become a problem.

The backbone of flood protection is a system of levees or dikes or earthen dams, which hold the waters of the Mississippi River within or approximately within its channel. These dams can be constructed only of the soil where they are located because any other type of construction would cost far more than the values protected. The construction of levees with this soil is fraught with many difficulties on account of the nature of the earth and the foundations



"B" TYPE CATERPILLAR LEVEE MACHINE

PROPERTY OF INNES CONTRACTING COMPANY. LEVEE WORK AT RICHARDSON POINT, RED RIVER, ARKANSAS. THREE-YARD SCRAPER, 85-FOOT BOOM. A CONVERTED "BUCYRUS" STEAM-DRIVEN MACHINE, NOW AN OIL-BURNING DIESEL ELECTRIC OUTFIT. FEBRUARY 11, 1929.

AUXILIARY DRAG LINE LEVEE-BUILDING MACHINE NO. B-8

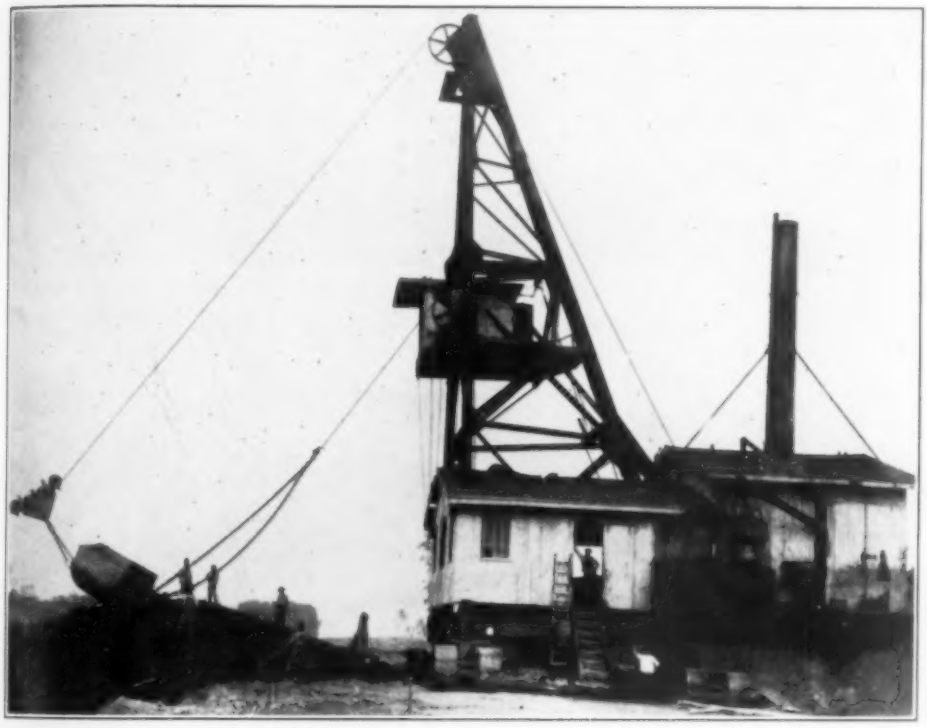
SHOWING LEVEE WITHOUT BANQUETTE BEING LEVELED TO BANQUETTE GRADE IN ADVANCE OF ENLARGEMENT. OCTOBER 19, 1921.

MACHINE C-6 IN OPERATION

HAYTI, MISSOURI. NOVEMBER 22, 1928.

encountered, but these difficulties must be overcome with the materials at hand since, as stated above, the use of any artificial material is too expensive to be permissible.

The earth which serves as foundations for the levee is the same alluvial material that forms the body of the levee. It is true that this varies somewhat, but none of it is any too good. It may be black clay, called locally buckshot, or sand or fine silt. Usually it is a mixture of sand and silt. It is more or less porous and will not bear excessive weight. Sometimes levees when built to the height desired—from twenty to thirty feet—will sink on the foundations. This may be accompanied by the rising of earth near by or there may be no indication at all where the levee material goes. In such cases apparently the foundation acts like a tube of toothpaste and material is squeezed out at some distant point which is never discovered. When subsidence is accompanied by a raising of nearby material the defect can sometimes be remedied by loading with earth the place that rises. Usually about all that can be done is to keep putting material on the levee until equilibrium is established sufficiently to permit the levee to be raised to the grade desired.



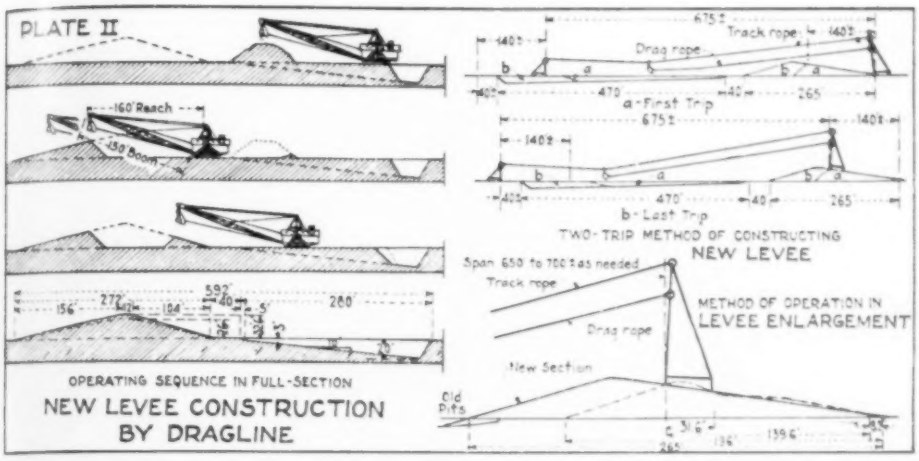
TOWER EXCAVATING LEVEE-BUILDING MACHINE C-7

SHOWING MACHINE ON BANQUETTE ENLARGING LEVEE.

The porous fundations permit water to percolate under the levee and come up on the land side. This is very dangerous if the water moves fast enough to transport material with it because such a process will soon create a cavity under the levee. A cavity underneath will of course cause the levee to drop and turn

C–6 BUILDING BANQUETTE
White Hall, Arkansas, 1924.

MACHINE C–6 IN OPERATION
Hayti, Missouri. November 22, 1928.



the flood waters loose over the land. The rate of this underground percolation is kept down by making its path long enough to preclude fast enough movement to transport material. This is produced by making the base of the levee wide enough. And the base always has a "muck ditch" in it to cut off lines of seepage and lengthen the paths of percolation.

When water moves under a levee too fast it is indicated by a "sand boil" behind the levee. This is a bubbling up of water carrying sand. When a sand boil starts it must be stopped promptly. The method used is to build with sand-bags a circular well around the sand boil. The water rises in this well and creates a hydraulic head against the percolating water so that its velocity is slowed down to the point where it can not carry material from underneath the levee. When there is a major highwater in the river and the water has risen to near the top of the levees, at places where foundations are not good, back of the levees, the adjacent territory will be sprinkled with these sand-bag wells to nullify the danger from sand boils. At such times all levees are patrolled and watched night and day for evidences of weakness.

Seepage through the levee itself occurs

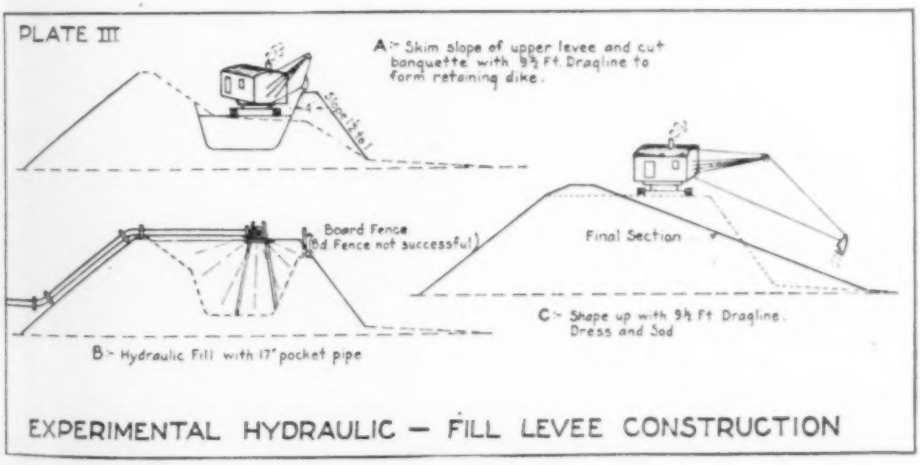


PLATE III
A:- Skim slope of upper levee and cut banquette with 9½ Ft. Dragline to form retaining dike.
Slope 4 to 1
Board Fence
(Sod Fence not successful)
B:- Hydraulic Fill with 17" pocket pipe
Final Section
C:- Shape up with 9½ Ft Dragline. Dress and Sod
EXPERIMENTAL HYDRAULIC — FILL LEVEE CONSTRUCTION

U. S. DREDGE *OMEGA*

BUILDING NEW LEVEE AT MOUND LANDING CREVASSE. SEPTEMBER 29, 1927.

CONCRETE REVETMENT, HUFFMAN, ARKANSAS

OCTOBER, 1927. SLABS PLACED ON BANK WITH DERRICK BOAT.

when water rises high against it. This like a sand boil must be kept down to safe velocities. This is accomplished by having the levee thick enough and broad enough at the base to inclose the line of saturation.

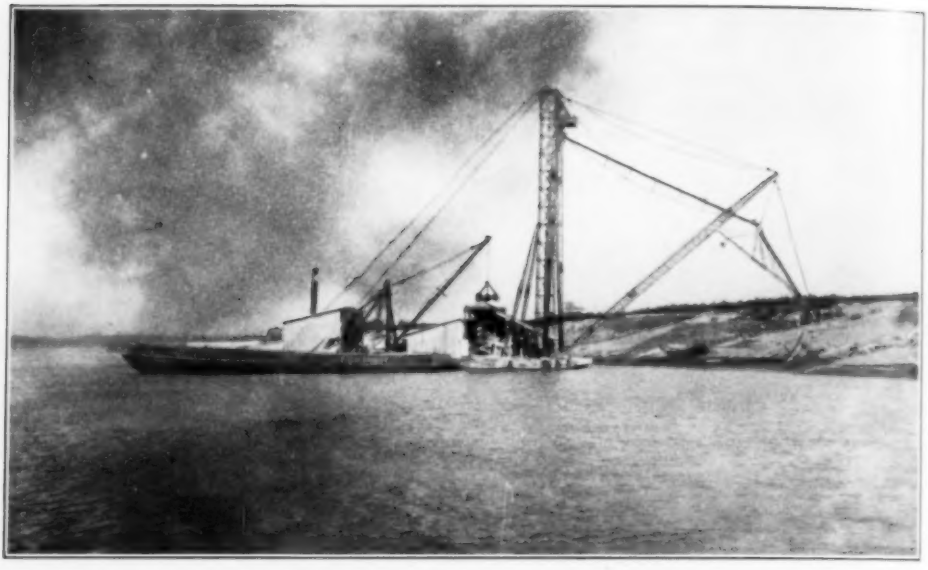
A wet levee will sometimes slough or slide; that is, the earth becomes so saturated that great portions of it slide off. The sections used are designed to be large enough to prevent this, but at times wet places that might slide have to be plastered with sand-bags placed as an emergency measure. If the sliding is too bad it may be necessary to construct an emergency loop around the bad place. This must necessarily be an improvised substitute levee made with sand-bags or earth held up with lumber.

The surest way to prevent accidents is to have the levee high enough and broad enough to preclude dangerous percolation, seepage or sloughing. But muskrats and other small animals may bore holes in a levee and make it unsafe. However, abundant material in the design is the best that can be done, and this is limited by cost. Sodding and careful maintenance by preventing weeds and trees from growing on the levee help to avoid failures. Cattle must be kept off a soft levee so that their hoofs will not destroy the sod which aids in keeping the levee firm.

The levees now being constructed in the Mississippi Valley are from twenty to thirty feet high. They are ten feet wide on top and from two hundred to three hundred feet wide at the base. These levees are quite stable and safe. Their construction is an enormous job. Millions of yards of earth must be scraped up and placed to form these dikes. The river below Cairo, Illinois, is about a thousand miles long and for the greater part of this length there are levees on both sides of the river. It is true that the old levees are there and

CONCRETE REVETMENT OF PREPARED SLOPES

BY PAVING WITH CONCRETE PLACED *in situ*. GILES BEND, LOUISIANA; CONCRETE PLACED IN 1924. OCTOBER 3, 1929.



FLOATING CONCRETE MIXER AND TOWER BARGE NO. 1712

SHOWING PLANT PLACING CONCRETE PAVING *in situ*. WILL PLACE CONCRETE 100 FEET FROM WATER'S EDGE AND 40 FEET ABOVE WATER. OCTOBER 19, 1921.

that most of the length requires only the raising and enlargement of the old levees. However, these are being made almost twice as large as they have been. In addition, in many places entirely new levees are being constructed.

When levees were first built the work was done by hand labor with picks and shovels and wheelbarrows. As they grew larger mule teams and scrapers were used. This levee construction was required to be carried up in layers two or three feet thick. Mules walking over the materials placed packed each layer and this resulted in the best kind of levee. Later mule and scraper work was supplanted by machinery because the amounts of earth to be moved were too great to be handled except by machinery within the time required and at the cost permitted. Machine work probably does not produce a levee equal in quality to the old levees but the increased size of modern levees more than compensates for any possible loss in quality.

Now that such enormous quantities of earth must be moved to carry out the adopted flood control project intense study is being given to earth-moving machinery with a view to the development of the best type for building levees. The necessity of moving the contents of a levee over a considerable distance must be kept in mind. Specifications prohibit digging and leaving unfilled borrow pits too close to the levees because of possible seepage, percolation and foundation troubles. The greater part of the levee work is done by contract, and there is keen competition among contractors. All the engineering ingenuity of these contracting firms is at work devising new types of machinery and new methods of operating types in existence.

Levee building machines include the following general types: drag line, floating clam shells, tower machines and hydraulic dredges.

In addition, levees are built with wagons and scrapers, with tractors and trailers and with industrial railroad tracks and derricks.

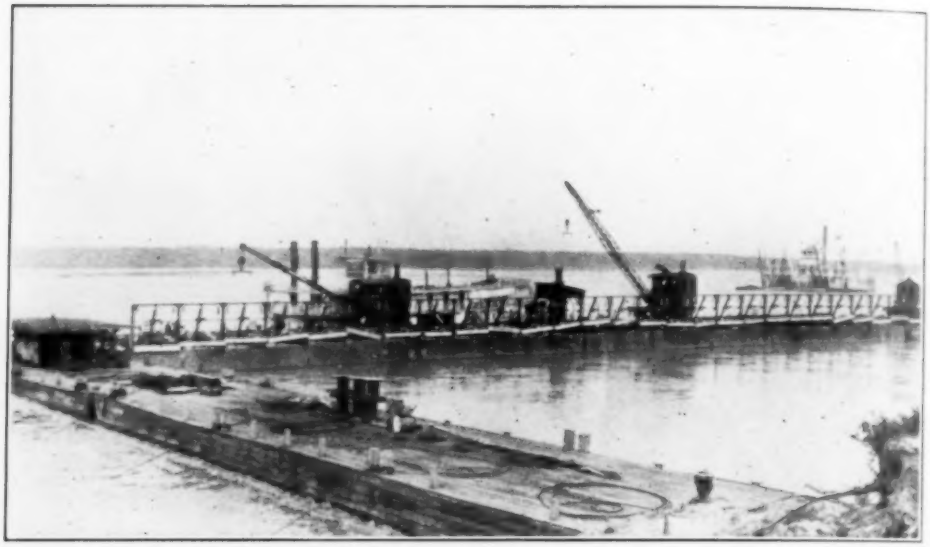
CONCRETE MAT-SINKING PLANT
IN OPERATION AT CAULK NECK, ARKANSAS. OCTOBER 13, 1927.

The drag line machine consists of a derrick on caterpillar or other treads having a long boom of moderate lifting power. A bucket or scraper swinging from the end of the boom scrapes up the earth by direct pull from the derrick engine. Then the boom has to lift only the material, swing it over the levee and drop it into place. Some double handling may be necessary.

Floating clam shells have a very long boom, dig the earth with a clam shell bucket, swing it over the levee and dump it in place. These require a ditch with water in it from ten to twelve feet deep. Since the specifications do not permit such a ditch too close to the toe of the levee, these machines must have a very long boom. Even with the longest boom that has yet been devised, some of the material must be handled twice and this increases the cost.

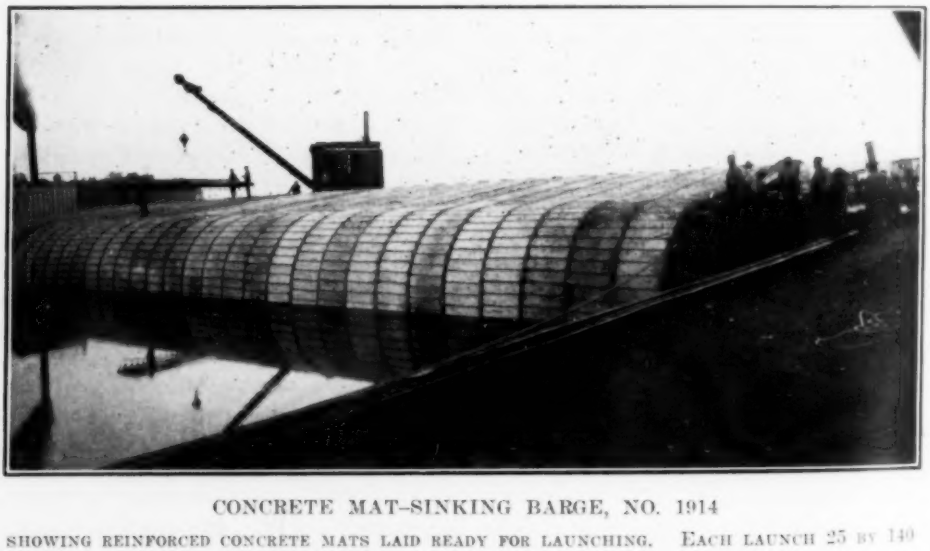
Tower machines consist of a main tower back of the levee and a smaller support out in front of the toe of the levee. Both these towers are on wheels or skids of some kind. A line stretches between them and from it swings a bucket scraper device. The engine at the base of the higher tower pulls lines which carry the drag bucket empty to the smaller tower. It is then dragged toward the levee, filling from the borrow pit and dumping into the levee section. These machines were designed to fit the requirements of levee building, which include a wide borrow pit, shallow toward the toe of the levee and growing deeper as the distance from the levee increases. This machine is essentially a dry earth machine and builds levees of dry material which settle and are dry within the time required.

Hydraulic dredges can be used to build levees, but conditions have to be suitable if the construction is to be cheaper than can be accomplished by dry method machines. In addition the earthen dike must be carried up in layers in such a way as to permit drying out and proper settlement and compacting. Earth can be moved more cheaply by hydraulic method than by any dry method, but flowing wet material will



CONCRETE REVETMENT, HUFFMAN, ARKANSAS

OCTOBER, 1927. HEADER BLOCKS READY TO SINK.



CONCRETE MAT-SINKING BARGE, NO. 1914

SHOWING REINFORCED CONCRETE MATS LAID READY FOR LAUNCHING. EACH LAUNCH 25 BY 140 FEET. OCTOBER 18, 1921.

not settle in a levee section just in the shape desired. This results in material flowing out of the section paid for, so that the actual yardage paid for may cost more than an equal amount of yardage placed by a dry method.

The Mississippi River perpetually flowing through its valley makes its own channel. It scours at places and deposits at other places, depending upon the velocity of the water and the way in which the current impinges upon the banks. In concave bends the banks are continually crumbling away, while on convex banks depositing processes are going on. Thus the river gradually changes its shape and location wandering through the ages from one side of the alluvial valley to the other side. There is no such thing as a permanent fixed location of the river for all time. This moving process and caving away of banks periodically destroys levees located alongside up and down the river. Levees like buildings in cities must be considered of limited life. A levee is generally located sufficiently far from the river bank to give it not less than a thirty-year life. Usually it is more economical to move a levee than to prolong its life by stabilizing the bank of the river and thus retarding the natural processes of nature. However, at places it is expedient to stabilize the river bank and this is accomplished by means of revetments and bank paving.

Revetment is made in two ways, *viz.*, with willow mats and with flexible concrete mats. The mat is placed below low water, lying on the side and bed of the river to prevent scour and undermining. Above the mat the bank is paved with concrete or stone to prevent the washing away of the bank above the low-water line. Mats stay in good condition something like eighty years; there is considerable durability in them. However, they are much more expensive per linear foot of river than levees, and it is for this reason that levees are usually moved back in preference to revetting the river bank.

CONCRETE MAT–SINKING PLANT

SHOWING HULL AND SUPERSTRUCTURE.

NEW ORLEANS RIVER DISTRICT

LAYING OF CONCRETE MATTRESSES FROM BARGES.

A willow mat is made of young willow trees having a diameter of from one to three inches. These are bound together into a fascine or bundle from ten to sixteen inches in diameter. The fascines are tied together side by side with wire cable and poles until a mat is formed some 1,000 feet long and 300 feet wide. This construction is accomplished by a plant specially designed for the purpose. The mat is woven continuously on barges placed perpendicular to the bank of the river. As the weaving progresses the mat is slid into the water where it floats alongside the bank. After a mat is completed it lies floating alongside the bank for 1,000 feet of bank length. Then barges loaded with stone are placed alongside the mat. The stone is thrown on top of the mat and as the mattress sinks the stone barges float over it. Thus it is loaded with stone until it rests on the bottom. Being flexible it sinks into place in the shape of the bed and underwater bank of the river below low-water line.

After a mattress is in place the bank above is graded either by hand or by hydraulic jet until it slopes back from the water line with a stable slope. On this graded bank either concrete paving or stone paving on a gravel base is laid up to the top of the natural bank of the river. The levee line may be located either immediately on the high bank of the river or from five to ten miles back from the actual bank.

When the supply of young willows available for mattress work began to become scarce, a flexible concrete mat was devised which costs about the same as a willow mat and serves the same purpose. There are two types of concrete mattresses in use. One is composed of reinforced concrete slabs one foot by four feet in size tied together with wire with butt joints. The other type consists of larger concrete slabs five feet by eleven feet, overlapping each other in shingle fashion and also tied together with wire. These concrete mattresses are formed on barges where the wiring together of slabs is done. From the barge the mat is slid off into the water and sinks of its own weight. A concrete mattress is laid from

the bank line perpendicular out into the river. Like the willow mattresses these concrete mats are flexible and assume the shape of the under-water bank and the bed of the river.

The greatest bank caving is caused by the bank under the low-water line scouring out. The weight of earth above causes the higher bank to drop into the river. If the mattresses protect the under-water bank and extend well out into deep water this scouring under effect is eliminated. Of course there is also bank wash above low-water line but this is relatively small compared to huge masses of bank dropping into the river from under-water scour.

Revetment such as is described is used at critical points on the river to protect levee lines where it is inexpedient to move back these lines. At places towns and cities are located on the river banks and at these places the moving back of levees is impracticable. Greenville, Mississippi, is on the bank of the river and its levee must be and is protected by several miles of bank revetment. In a location of this kind it is essential to keep the bank revetment well maintained to prevent a disaster due to caving banks.

The City of Memphis is on high ground, not the alluvial valley proper, but the river currents impinge upon the edge of this large city and attack its foundations. Huge masses of earth have subsided toward the river at Memphis, taking down with them structures and improvements. These subsidences are being opposed by bank revetments of mattresses laid along the river bank as described.

New Orleans harbor is revetted. This large city is protected by a wide levee twenty-five feet above low-water stage. The city itself is all about twenty feet below the highest stages of the Mississippi River. The revetment in the harbor is extensive and has to be kept in good repair to prevent the banks from caving into the river. The levee line is immediately on the bank of the river, and high buildings, docks

MATTRESS PARTIALLY CONSTRUCTED

TO BE USED FOR BANK REVETMENT.

MOORING BARGES

AT PRINCETON, MISSISSIPPI. OCTOBER 18, 1921.

and other improvements are located on the very banks of the river. After the flood of 1927 there was unusual scour in the harbor followed by serious settlement of expensive docks. New repair mats were placed to stop this.

In addition to the levees and revetments for flood control purposes, a spillway is being constructed above New Orleans to let out from the main river sufficient water to reduce the amount that can possibly pass that city down to a quantity that can pass with absolute safety. This spillway is located at Bonnet Carre, about twenty miles above New Orleans. It consists of a masonry sill and movable dam 7,700 feet long and a floodway within which the discharged water can flow in safety to Lake Pontchartrain where it will be harmless. The dam can be removed when stages become excessive. Thus enough water will be permitted to escape to reduce the water in the main channel to the amount considered safe. The floodway stream will be over a mile wide and from ten to fifteen feet deep, flowing at velocities of from two to three and one half feet per second. This is of course a large river in itself. The main river at this point is wide and from sixty to one hundred feet deep. It flows at velocities of from five to seven feet per second. The main river is about five times as large in capacity as the spillway.

The adopted flood control project for the alluvial valley of the Mississippi provides for the expenditure by the United States of $325,000,000. This expenditure is to be made over a period of ten years. It is contemplated that after completion the adopted project will protect the greater part of the valley against the maximum flood predicted as possible. While the greater part of the area is to be thus protected, more especially are the parts that include the greater values to be protected. The centers of population and commerce are more important than areas alone.

After the pending annual appropriation ($35,000,000) has been expended there will have been spent about $100,000,000 toward the contemplated protection. At that time protection against any flood reasonably probable will have been completed. Already great additional protection has been afforded by the work of the government. During the spring of 1929 one of the highest waters ever recorded passed safely down the river into the gulf without a crevasse on the main river. The fact that there was no disaster caused this flood to pass unnoticed by the general public. It was the greatest flood that ever passed through the valley without crevasses and serious damages.

No one who has not traveled all along the levee lines between Memphis and New Orleans can realize the immense public work that they represent. Before the federal government set its hand to the work of flood control two years ago, the levee system already constructed stood as material evidence of the great energy, enterprise and determination of the people who live along the banks of the mighty stream. The whole world seems to know of the dikes of Holland, and of the tenacious courage and indomitable industry of the Dutch people. Some day when the proper literary genius comes along the story of the levees along the Mississippi will find its way into the vision of the world to the everlasting credit of the people of the great lower valley.

It is well for all to know that the federal government has never set its hand to the control of floods in the valley of the Mississippi as much as it did less than two years ago. While it did in the past concern itself to some extent with floods, it devoted itself primarily to the question of navigation. It gave assistance to levee building, but the bulk of that work has been done by the local people. The federal government's activities in levee building were first induced by the belief that to confine the flood waters to the channel would increase its depth and so improve its low-water condition as regards navigation. In the long run that belief may be correct, though men may have to wait over a long period before the results become very apparent.

It is the belief of many of the best informed that the levees along the main stem of the river have reached the ultimate height to which they should be raised. The failure of a high levee invites greater disaster than that of a low one. The denser population behind a levee and the greater improvement of the land, both of which are to increase with the prosperity and greatness of our country, cause the future to frown heavily on high levees. The limit of height seems to have been obtained from an economical view-point also, for the greater the height the greater the unit cost. The limit of height also is indicated in many places now by the tendency toward excessive settlement of foundations. Every consideration points toward keeping the levees as low as possible.

As means of keeping the levees low we have three courses of action: diverting water from the main channel, keeping it back from the main channel by storage reservoirs on the tributaries and straightening the main channel. These means are all very expensive and must be carefully considered before final decision as to the extent that any or all will be used, and how they will be used. We are in position to decide the diversion question were it not involved with the reservoir question to which we wish to give further consideration. The straightening of the channel must wait; we can not do it now.

Our hope is to solve this problem satisfactorily. There are three phases of it that require careful consideration as well as physical research. They are: (1) Economical bank protection to stabilize the levee system and improve the channel conditions for navigation, (2) storage reservoirs and (3) increased channel capacity by the elimination of bends.

Of these three phases of the question, (1) and (3) are interdependent, (3) not being practicable unless (1) is solved. I regard the development of an economical method of bank protection as the real problem of the Mississippi both as regards navigation and flood protection.

Photograph by E. D. Wilson, Arizona Bureau of Mines

SHARPLY ERODED VALLEYS IN ISOLATED MOUNTAINS OVER VALLEYLESS AGGRADED PLAINS
SOUTHWESTERN MOST ARIZONA.

PHYSIOGRAPHIC CONTRASTS, EAST AND WEST

By Professor Emeritus W. M. DAVIS
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II

Washes and Wadies

The dry channel beds of valleyless intermont troughs and basins, commonly called "washes" in the West, are the equivalent of the "wadies"[19] of the Sahara. They are as little known in the East as detrital fans. The larger washes lead down detrital-fan radii from valley mouths in the mountain margins, but myriads of little branch washes have their heads on the gentle declivity of the detrital slopes. The last flood that swept down a wash left the bed covered with gravels and sands as the flood water slowly drained away. The next flood will take up the gravels and sands as it rises, carry them farther forward toward the trough-floor plain as it runs and replace them with new gravels and sands brought from farther up the slope as it falls. In the long dry spells between floods, the convectional whirlwinds of hot noons lift the finer detritus from such washes as they happen to cross, carry it a short distance in the air and let it fall, hit or miss, on the plain. The persistent presence of drainage slopes and especially of the myriad little branch washes proves, however, that running water is the dominant agency of transportation, even though intermittent in its action.

Where the "wash" of an intermont plain has a cobbly or gravelly bed, its braided channel is broad and shallow; where it is cut in silt it is usually narrower and deeper. A silt channel may, indeed, be so deep as to be mistaken in the dry season, when only a little stream trickles along its floor, for a young valley by an observer not familiar with the enormous difference between the low- and high-water volumes of rivers in arid regions; but when a master flood comes along, the entire channel will be filled to overflowing. At such times the flood temporarily enlarges the already large channel by lifting silt from the bed, so that the depth of the flood current is added to downward at the bottom as well as upward at the surface, and the downward addition may be even greater than the upward. An extraordinary record of a rising and scouring flood has been made for the lower Colorado at Yuma by the engineers of the U. S. Reclamation Service. An ordinary low-water record shows that the river there stands at 115 feet, gauge height, with a breadth, partly occupied by a 200-foot sand bar, of 480 feet, and a maximum depth of 6 or 8 feet in a main channel about 100 feet wide. During a flood in June, 1921, the river rose to a gauge height of 131 feet, with a breadth of 570 feet, a general depth of 60 feet and a maximum depth of 66 feet in a channel about 300 feet wide. The discharge was then 186,000 cubic feet a second, or 155 times greater than the low-water discharge. The significant item here, in

[19] The Arabic word for river, of which *wady* is the anglicized form, was long ago carried by the Moors into southern Spain, where it still survives in the first syllable of several river names, such as Guadalquivir, Guadalajara, Guadalupe. The interchangeable initial consonants in *guad* and *wady* are also seen in the more Latin words, *guarantee* and *guard*, and their more English doublets, *warranty* and *ward*; also in the French *Galles* for the English *Wales*.

connection with flood-scour of channel beds, is that while the flood surface rose 16 feet, the flood bed deepened 42 feet; that is, the scour was over two and a half times the rise!

Examples of Intermont Troughs and Basins

A typical and valleyless intermont trough-plain, from 10 to 30 miles across and containing several playas, is found in southeasternmost Arizona, where it is known as Sulphur Springs Valley. It is somewhat irregularly bounded on the east and west by mountain ranges of moderate height, believed to be upfaulted blocks, in which numerous valleys have been elaborately eroded; but there are practically no valleys on the plain itself through all its length of over 90 miles. As one travels along its smooth surface, the even horizon appears to recede as it does at sea. Indeed, the curvature of the earth seems to be recognizable there by the appearance of distant cottonwood trees or ranch windmills over the even skyline, before the ground below them comes into sight. The nearly level surface is crossed near its north and south ends by two lines of the Southern Pacific Railway, which run in long, straight-line tangents. The broad surface of this plain is better covered with grassy herbage than is the case with more desert plains farther west. Its general features have been well described in a study of its ground-water supply.[20]

Far to the west in the subhumid climate of southern California, a fine example of a well-enclosed oval intramont basin, in contrast to a long intermont trough, is furnished by San Fernando "Valley," next northwest of Los Angeles. It measures about 25 miles east and west by 12 or 15 miles across, and is surrounded by mountains of moderate or small height on all sides, except for two narrow openings: one on the northeast which is blocked by heavy detrital fans from the higher mountains on the north, and the other on the southeast which remains open. The mountains are, as usual, well dissected by true valleys of erosion, but all the valleys end at the mountain base line, where their channels are continued forward on one radius or another of the laterally confluent detrital fans of low gradient, all of which merge in the central plain of the basin floor. The mountains on the north being higher than the others, their fans are the largest and they push the central plain to an eccentric position near the southern, lower range; and the northern mountains being largely composed of resistant crystalline rocks, the usually dry channels of their long fans supply abundant hard-rock boulders for rock crushers, the high scaffoldings of which are familiar features thereabouts. All the inflow of the wet-weather streams unites at times of flood to form Los Angeles River, which when running finds escape through the open southeastern gap. In the gap stands the growing city of Glendale which, Western fashion, announces its name to the arriving visitor in electric signs hanging over the main thoroughfares, and adds, with the aggressive self-consciousness of new and ambitious Californian cities, "Watch us grow." The San Fernando Plain, a land of arid bush and scanty pasture in its native condition not many years ago, is now largely occupied by towns, orchards, rose gardens and fields; but it has lately been acquired, as a sort of safety valve, by the irrepressible City of the Angels, hence one may expect that in a few years more it will be covered with open-spaced residences and close-set business blocks.

Holes in the Inyo Mountains

Two pronounced examples of exceptionally small, down-flexed desert basins, typically intramont, are found in the

[20] O. E. Meinzer and F. C. Kelton, "Geology and Water Resources of Sulphur Spring Valley, Ariz.," U. S. Geol. Surv. Water-supply Paper No. 320, 1913.

southern part of the long Inyo-White Mountain Range, which rises near the oblique Nevada boundary of California, next east of the Sierra Nevada. One of the basins, measuring only 12 by 5 miles, is known as Deep Spring "Valley," but as it is without outlet it might be better called Deep Spring "Hole," for that expressive term is already officially authorized in naming Jackson Hole in the Rocky Mountains of Wyoming. The hole in the Inyo Range is caused by the down-flexing of a portion of the mountain mass on the northwest against a nearly rectilinear and well-dissected fault scarp on the southeast.[21] The aggraded floor of the hole has an altitude of 4,900 feet, and lies from 1,000 to 3,000 feet below the highlands of the range. Its fans are supplied chiefly from valleys cut in the down-flexed slope on the northwest; and the streams in those valleys work, when they run, as energetically as if their lower courses would lead all the way to the ocean. But they are doomed to early disappointment—they end in a shallow saline lake on the valleyless floor of the hole.

Another deep hole, thirty miles to the southeast in the same range, known as Saline "Valley," is somewhat larger, as its floor measures twenty-five by ten miles. It has a moderately dissected fault scarp of unusual strength on the southwest, which rises fully 6,000 feet over a small lake at 1,000 feet altitude on the floor of the hole. It is difficult to imagine what kind of subterranean movement within the earth's crust can have caused these local cave-ins or failures of upheaval in the Inyo range-block. The collapse of cavern roofs can not be appealed to, because limestones do not enter largely into the make-up of the mountain mass.

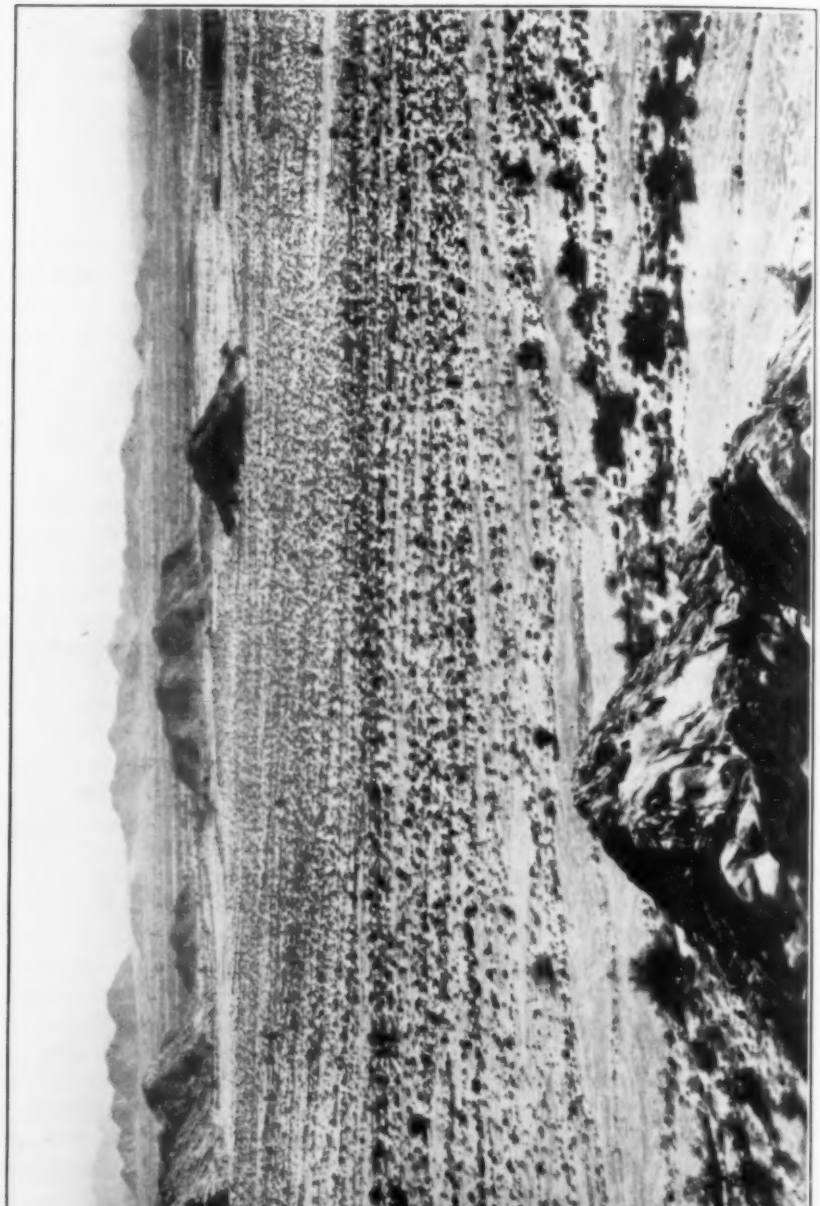
The Great "Valley" of California

The largest example of an aggraded, intermont trough in our Cordilleran country, and one of the best in the whole world, lies beyond the Great Basin in California, where it occupies a down-flexed or down-faulted depression between the lofty Sierra Nevada on the east and the much lower Coast Ranges on the west. It is, of course, known as a "valley," although a French visitor appropriately described it as *la plaine intérieure* over 60 years ago.[22] This magnificent domain, measuring over four hundred miles along its slightly curved length by from 25 to 60 miles in breadth, is a well-defined physiographic unit, for its enclosing mountains are confluent at both ends. It consists, except where the Marysville volcanic buttes rise in its northern part,[23] of a great number of smaller and larger detrital fans of faint slope, between which the axial plain where the fans from the two sides merge lies nearer the lower Coast Ranges, being pushed there by the larger fans from the higher Sierra. The basin is drained by the Sacramento from the north and the San Joaquin from the south to a common westward outlet at the mid-length of the Coast Ranges. Both rivers are valleyless in their course along the plain, and most of their branches are valleyless also, though some of them have excavated shallow valleys of erosion in the upper part of their fans. Until a very late geological period the westward outlet was a trunk river, which may be provisionally named Golden River and which, on its way to the Pacific, ran through gorges of erosion in two Coast Ranges and across an inter-range trough plain between them. In consequence of a slight submergence of its district, the outer gorge is now drowned in the Golden Gate; part of the inter-range trough plain is flooded to small depth

[21] W. J. Miller, "Geology of Deep Spring Valley," *Journ. Geol.*, 36: 510–525, 1928.

[22] E. Friquet, "Coup d'oeil sur la constitution géologique . . . de la Californie . . .," *Bull. Soc. Géol. France*, 23: 347–371 (see p. 365), 1867.

[23] Howel Williams, "Geology of the Marysville Buttes, California," *Univ. Calif. Geol. Bull.*, 18: 103–220, 1929.



Photograph by E. D. Wilson, Arizona Bureau of Mines

ISOLATED MOUNTAINS AND VALLEYLESS AGGRADED PLAINS

IN THE DESERT OF SOUTHWESTERN MOST ARIZONA. THE LINES OF BUSHES INDICATE THE COURSE OF DRY WASHES.

in San Francisco Bay, and the inner gorge is drowned in Carquinez narrows, above which the shallower waters of Suisun Bay overlap part of the inner Great "Valley" plain. The shallow Suisun overlap was originally larger than at present, for it has been much encroached upon by the double delta of the two betrunked rivers.

The great interior plain was a grazing region under Spanish-Mexican dominion; it became a farming country in the early days of California's statehood; it is now largely a fruit country. An extensive area in its northern part has been elaborately mapped by the topographers of the U. S. Geological Survey on a scale of two inches to a mile, with five-foot contours. One of the most interesting items in the recent history of the plain, an item intimately connected with its valleyless form, is the conflict between the farmers on the plain and the miners on the adjoining uplands of the Sierra Nevada. The latter "hydraulicked" the auriferous gravels of the uplands so actively during the third quarter of the last century that the farmers' fields along the valleyless rivers were in danger of being buried under the artificially increased outwash of detritus. Action through the courts to avert this danger was sought by the farmers and secured in 1884, and in 1893 a California Débris Commission was appointed by Congress to safeguard the nominally navigable rivers from obstruction by the downwashed "tailings." A quantitative study of the gravel outwash and of its aggradational effects down stream from the hydraulicked uplands, where the scars of the washing are still prominent features of the Sierran landscape, was one of the latest investigations undertaken by Gilbert.[24]

[24] G. K. Gilbert, "Hydraulic-mining Débris in the Sierra Nevada," U. S. Geol. Surv. Prof. Paper 105, 1917.

An Orange Belt in Southern California

A smaller but good-sized and heavily aggraded intermont or perhaps intramont trough, some sixty miles in length, lies in southern California. Its northern border is formed by the high, east-west San Gabriel Mountains and their eastward extension, beyond the curious oblique depression known as Cajon Pass, in the San Bernardino and San Gorgonio Mountains. Its southern border, 10 or 15 miles away, is formed by an irregular series of uplands and mounts of moderate altitude. A series of great detrital fans slant southward from the loftier northern range; they are relatively steep, coarse textured and dry near their heads, but become nearly level, fine textured and moist at their far ends, ten miles or more forward. The fans from the southern uplands are relatively small; hence the physiographic axis of the trough is pushed close to its southern margin; and there runs the Santa Ana, usually of reduced volume yet the largest river in the southern part of the state. It has, for much of its length, cut a shallow valley in the trough floor, probably because of its recent success in trenching a gorge through the low range of the Puente Hills, which encloses the trough on the west. But when Californians speak of the "Santa Ana Valley" they do not refer to this little valley of shallow excavation, but to the heavily aggraded trough-plain in which the little valley is eroded.

The trough floor was, in its native state, not many years ago, an unproductive waste, an "idle wild." It has been rapidly converted by intensive cultivation into one of the most fruitful districts of our entire country, and is now occupied by an exceptionally well-conditioned population. San Bernardino, Riverside and Redlands are near its east end; the unusually beautiful city of

Pasadena is at its west end, with Los Angeles beyond low hills ten miles to the southwest. Many smaller communities occupy intermediate situations. The long fans are largely covered in their upper half with orange groves, which are irrigated with ground water pumped up from the coarse detritus of the fan heads. Much of the lower, and nearly level, distal extension of the fans, where the water-table is near the surface, is farmed, but the lower part of some of the eastern fans, where the surface is exceptionally sandy, is occupied by "the largest vineyard in the world," one of California's best-justified superlatives.

No Aggraded Basins in the East

In the northeastern states, north of the Missouri and the Ohio rivers, many plains were built up over an uneven land surface during the Glacial period. Some of them are plains of till, which may be regarded as delta-sheets formed beneath the thinning margin of ice-sheets, where more detritus was brought than could be dragged farther forward. Others are gravel and sand plains, formed where outflowing streams of ice-water deposited part of the detritus that they had gathered in their subglacial courses. There are also many small plains formed by the inwash of detritus into little lakes of glacial origin. These plains are purely climatic in origin, not at all orogenic.

There are, indeed, no recently down-faulted and aggraded basins in the East such as those above described and many others like them in the West. The only approach to an Eastern homologue of the Western basins is found in the small, shallow, water-filled hollows, known as "sunk lands," that were formed by slight subsidences, perhaps due to deep, cavern-roof collapses, in the northern part of the Mississippi flood plain at the time of the earthquake of 1811, of which Fuller has prepared an admirable account.[25] Two of the hollows hold lakes, Reelfoot, 13 miles long, in northwestern Tennessee; and St. Francis, over 25 miles long, in northeastern Arkansas; both are of trifling depth. The great Mississippi flood plain itself, in which these sunk lands occur, is in certain respects analogous to the axial flood plains of the Sacramento and San Joaquin rivers in the Great "Valley" of California; but in other and more important respects the flood plains are unlike. That of the Mississippi is the smooth floor of a true valley of erosion in the Gulf coastal plain, which gained great width between its limiting valley-side bluffs on the east and west by reason of the great size of the river that eroded it; and that river was, for a time, doubly great, because during the invasion of our northern states by Canadian ice-sheets they constrained a great part of the drainage, which normally belongs to the St. Lawrence and Hudson Bay River systems, to flow southward via the lower Mississippi to the Gulf of Mexico. Although small areas of outwashed deposits are formed along the base-lines of the bluffs on the east and west by the streams that there descend from the enclosing uplands, these deposits do not by any means dominate the course of the Mississippi as the courses of the Sacramento and San Joaquin are dominated by the fans outwashed from the Sierra Nevada and the Coast Ranges, but on the contrary the Mississippi, by means of the lateral slopes of its own flood plain, dominates the small streams and tells them to sidle along the base of the bluffs until it is ready to come over and take them in. The Yazoo, nearly 200 miles in length, is the type for the world of such a stream. The Mississippi picks it up at Vicksburg.

[25] M. L. Fuller, "The New Madrid Earthquake," U. S. Geol. Surv. Bull. 494, 1912.

See also, W. A. Nelson, "Reelfoot—an Earthquake Lake," *Nat. Geogr. Mag.*, 45: 95-114, 1924, with fine airplane views.

Long Duration of Arid Erosion

In spite of the usual inactivity of streams in desert regions, they work with enormous energy when flooded and then accomplish a vast amount of erosion, transportation and deposition. This may be seen not only in the deep valleys that they have excavated in many mountain ranges but also in the construction of the great detrital fans along the mountain bases. Scores of thousands of years must have been thus occupied, for the fans were largely formed before the last Glacial epoch, as is thus known: During the moister climate of that time the northeastern part of the Great Basin was occupied by an extensive lake, nearly as large as the present Lake Michigan, to which the name of Bonneville has been given after the first explorer who recognized its high-level shore lines, reference to which has already been made. Great Salt Lake, a mere film of extremely saline water, now reserves for itself a relatively small part of the dried floor of Bonneville in the more arid climate of the present day. The shore lines of the extinct greater lake are strongly marked on the rocky flanks of several basin ranges where its waters were deep, as in the neighborhood of Salt Lake City, up to nine hundred feet above the present lake level. But in the shallower southern arms of Bonneville, where wave action was weak, the shore lines are lightly marked even on the detrital piedmont fans. Many of these faintly shore-scored fans are of great size; hence they must have almost reached their present size in pre-Bonneville time, and that time must therefore have been characterized by a fan-building or desert climate, like that of to-day, for a much longer duration than the post-Bonneville period, as was long ago made clear by Gilbert.[26] Discontinuity of valleys has therefore long been characteristic of the Great Basin region.

[26] G. K. Gilbert, "Lake Bonneville," U. S. Geol. Surv. Monogr. I, see pp. 91, 92, 1890.

Hanging Valleys in Fault-block Mountains

The most remarkable examples of discontinuous valleys in the Great Basin remain to be described. They are to be seen, opening at high levels above the adjoining trough floors, in the east-tilted Funeral and Panamint fault-block ranges that enclose the exceptionally low-lying Death Valley in southeastern California. Their origin appears to be essentially as follows. During an earlier episode in the history of these ranges, an episode characterized by a still-stand pause after partial up-faulting, well-opened valleys were carved in their flanks and appropriately large detrital fans must have been built forward in the adjoining down-faulted troughs, as in the background of Fig. 4. Since then a second episode has been introduced at a recent date by a further up-faulting of the range blocks and a further down-faulting of the troughs along much of their length, as in the middle of the figure. In consequence of the renewed movement the well-opened valleys, that were carved back of the original fault scarp during the previous episode of quiescence, now open into the air and have sharp clefts cut below their hanging mouths, while the depressed fans are buried under an accelerated discharge of detritus from the slightly steepened back slope of the range on the other side of the trough, as in the foreground of the figure. The little fans at the base of the new-cut clefts are manifestly much too small to contain the detritus that was eroded and removed in the excavation of the well-opened hanging valleys. Hanging valleys, opening into the air, are discontinuous with a vengeance! A greater contrast than that which they present with the steady-going Appalachian valleys can hardly be imagined. And clearly, the cause of the contrast is not to be found in any lack of mobility in the Western streams, when they are wet enough to run, but in an

FIG. 4. A THREE-STAGE DIAGRAM TO SHOW THE EVOLUTION OF A HANGING, FAULT-BLOCK VALLEY

IN THE BACKGROUND, A MATURELY ERODED FAULT BLOCK, WITH A LARGE FAN OUTWASHED FROM ITS CHIEF VALLEY INTO THE ADJOINING DOWN-FAULTED TROUGH. IN THE MIDDLE, THE POTENTIAL FORM OF THE SAME, AFTER FURTHER UP-FAULTING OF THE MOUNTAIN BLOCK AND DEPRESSION OF THE TROUGH; A SLANTING FAULT SCARP SEPARATES THE TWO PARTS. IN THE FOREGROUND, THE SAME AFTER EROSION AND DEPOSITION CONSEQUENT ON THE RENEWED FAULTING.

excess of mobility in the Western earth crusts. The sight of these young fault scarps under the hanging valleys makes one realize how wild the West still is, geologically, and how utterly unlike the geologically tamed East.

Where renewed up-faulting of this kind has recently taken place, the physiographic axis of the associated down-faulted trough lies for a time close to the scarp base of the uplifted block, as may be known from the occurrence there of salt marshes which ordinarily lie near the mid-line of the trough.[27] Between the cut-off valleys, now high in the air, and the alluvial cover of the depressed and buried fans, stands the newly exposed and little modified fault scarp of bare rock, which in Death Valley is inclined at an angle of 40° or 45° and measures from 500 to 1,000 feet in slanting height. The scarp transects the rock mass without regard to its complicated structure. The little detrital fans that have been built out on the new floor of the trough at the base of the fault-scarp clefts are, as above noted, of small volume compared to that of the high-standing valleys. A front view of some of the high valleys, narrow clefts and little basal fans suggests their likeness to the bowl, stem and base of a goblet. Be it noted, however, that, although many valleys are thus very distinctly truncated by renewed faulting in the Funeral and Panamint ranges, they are not so sharply cut off as are the numerous hanging lateral valleys above the glacially overdeepened fiord troughs of Alaska or Norway, or as the *vallcuses* that open abruptly in the sea cliffs of Normandy at mid-height above the cliff base; but they are more sharply cut off than the hanging valleys of Kentucky, above described, and they are certainly

[27] The recent and temporary displacement of trough-floor marshes or lakes has been described by A. C. Lawson in his account of certain modern faults along the east base of the Sierra Nevada, not far from Reno: *Bull. Seism. Soc. Amer.*, 2: 195, 1912. Another example is described by R. J. Russell in his account of the Warner Range of Northeastern California: *Univ. Calif. Bull. Geol.*, 17: 483, 1928.

astonishingly out of gear with their surroundings.

Various other examples of renewed faulting in fault-block ranges might be instanced of small or large measure. The most significant signs of small upfaulting are seen in low "eyebrow scarps," from 10 to 20 or 30 feet in height, cutting across piedmont detrital fans, somewhat as in Fig. 5. They run parallel with but stand somewhat forward from the base line of a fault-block mountain.[28] The subsurface displacements involved in the production of these low scarps cause earthquakes, as is already known from three historic examples, in spite of the shortness of our Western historic record. One was in Owens "Valley" at the eastern base of the Sierra Nevada in southeastern California,[29] this grand mountain range being the largest and perhaps the most irregularly complicated fault block in the West. The view of the tremendously dissected scarp in the southern part of the range from half height on the western flank of the Inyo Range across the intervening trough of Owens "Valley" is one of the grandest prospects that our country affords. Another quake-producing fault scarp was formed in 1887 in Sonora, Mexico, just south of Arizona, where its face averaged eight feet in height for nearly forty miles. A third was produced in Nevada in 1915.[30]

It is worth adding that eyebrow scarps are, like the fault-block mountains with which they are so closely associated, an American contribution to knowledge; and also that when Gilbert, their discoverer, showed an excellent one in the

[28] Many examples of recent fault scarps in piedmont detritus, variously complicated, are described by G. K. Gilbert, "Lake Bonneville," U. S. Geol. Surv. Mon. I, see pp. 343–355, 1890. Other examples are given by I. C. Russell, "Lake Lahontan," *ibid.*, Monogr. XI, see p. 275, 1885; also by A. C. Lawson, "The Recent Fault Scarps at Genoa, Nevada," *Bull. Seism. Soc. Amer.*, 2: 193–200, 1912.

[29] J. D. Whitney, "The Owens Valley Earthquake," *Overland Monthly*, 9: 130–140, 266–278, 1872.

[30] G. E. Goodfellow, "The Sonora Earthquake," *Science*, 11: 162–166, 1888; J. C. Jones, "The Pleasant Valley (Nevada) Earthquake of October 2, 1915," *Bull. Seism. Soc. Amer.*, 5: 190, 1915.

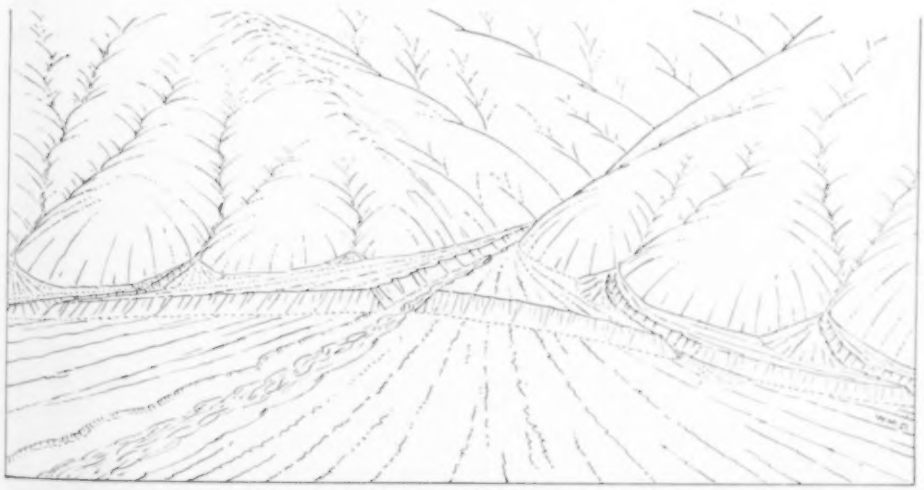


FIG. 5. A FAULTED ALLUVIAL FAN AT THE MOUTH OF A VALLEY IN A MATURELY DISSECTED FAULT-BLOCK MOUNTAIN. IN CONSEQUENCE OF A RECENT RENEWAL OF FAULTING, THE FAN IS TRAVERSED BY AN "EYEBROW" SCARP.

neighborhood of Salt Lake City to a party of European geologists who were touring the West after the International Geological Congress at Washington in 1893, the scarp was so great a novelty that they one and all refused for two days to accept his interpretation of it as the result of a recent fault: to them it was only "a gravel bank."[31]

Renewed faulting, of less recent date than in Death Valley but of much the same amount, has taken place in the great up-faulted, west-facing crustal block known as the Wasatch Range in Utah, at a point 15 or 20 miles north of Salt Lake City. The previously well-dissected and degraded mountain mass was there subrecently upraised and the large fans that must have fronted its well-opened valleys were depressed. The inferred fans are now out of sight under the piedmont alluvial lowland which borders Great Salt Lake; the broadly opened mountain valleys and the rolling uplands and highlands between them stand from 500 to 1,000 feet above the lowland. Sharp-cut gorges have been sliced in the battered fault-scarp below the uplifted valley mouths, from which small fans of a second generation are now growing.[32] An exceptional example of renewed fault-block upheaval is found in the long, heavily louderbacked Galiuro Range of southeastern Arizona, for there the detrital deposits, built forward from the flanks of the range after its first upheaval, have been raised with the range in its second upheaval and now share its renewed erosion.[33]

[31] "Biographical Memoir of G. K. Gilbert," Mem. Nat. Acad. Sciences, XXI, see p. 102, 1926.

[32] G. K. Gilbert, "Studies of Basin Range Structure," U. S. Geol. Surv. Prof. Paper 153, see p. 50, 1928.

[33] W. M. D. and Baylor Brooks, "The Galiuro Mountains, Arizona," *Amer. Journ. Sci.*, 30: 89–115, 1930.

Aridity, Detrital Fans and Irrigation

In consequence of its arid climate the great Southwest must irrigate its fields and orchards on the intermont detrital plains, and here the valleyless character of the plains is of great advantage. The streams from the larger mountain valleys are taken in hand at the valley mouths and led along major and minor distributing canals on the low-grade piedmont fans, the gentle, radial slopes of which are admirably adapted to this method of refreshment. Hence although the aridity of the region imposes the necessity of artificial watering before crops can be raised, it also provides, as if by way of compensation, a peculiar, valleyless land form on which artificial watering can be most easily accomplished; for, as above told, valleyless detrital fans are a characteristic, indeed, a necessary consequence of arid erosion in a mountain-and-plains region. The Mormons, our earliest settlers in the desert wilderness, industriously established their village communities wherever a suitable combination of mountain stream and piedmont fan could be found, and not a few of these communities years ago reached the maximum population that can gain a livelihood from the fields which they irrigate from the fan-feeding mountain valleys. Some of the communities utilized the high-level, mountain-flank deltas that were built up in the waters of Lake Bonneville; and inasmuch as all such deltas are now trenched by the streams that built them, their occupation demands a certain amount of engineering in the construction of canals which divert the streams some distance back in the mountains and lead them in canals of low gradient along the valley-side slopes to the high-standing delta plains.

All later settlers in the dry country follow the Mormon example. In recent years the U. S. Reclamation Service has, by building great dams to enclose large

reservoirs, greatly increased the area of the detrital plains upon which the rainwater falling on the mountains is now spread. But unhappily these beneficent projects have not always brought success to those who have striven to take advantage of them; the outlay involved before any profitable returns could be secured has proved ruinous to many a well-intentioned but ill-informed settler.

The Roosevelt Reservoir and the Phoenix Oasis

The Roosevelt Reservoir in east-central Arizona may be taken as a type example of its kind, for although its reservoir is not the largest that has been impounded, its irrigated area is said to be the most flourishing of all the Western reclamation projects. The reservoir is enclosed by a masonry dam which blocks a narrow, crosscut gorge in a fault-block mountain range, and there the united waters of Salt River from the highlands on the southeast and of Tonto Creek from the ranges to the north are held up in a great lake, 35 miles in length when filled to overflowing. The conserved waters are discharged westward along Salt River Valley, eroded through a well-dissected mountainous belt, largely composed of tilted lava sheets and ash beds, for some 30 miles to a broad intermont trough, where the river had through previous ages built up a broad, faintly sloping, detrital fan of 40 miles radius and of as great a frontal spread in its extension into the desert. It is upon this naturally graded detrital surface that a large area around Phoenix, the capital of the state, has been developed into a great oasis; but instead of bearing that appropriate name, the irrigated area is known as "Salt River Valley." That title is most unfitting, for it is wholly because of the unvalley-like convexity of the fan that irrigation has there been so economical and so successful. One might as well call the Mississippi Delta a valley, where it projects into the Gulf of Mexico! It is precisely because the real Salt River Valley of erosion ends at the mountain border and that the river thence onward runs, Western fashion, on a valleyless fan that the oasis was there located; and in order to tell the truth about this wonderful district a careful use of the old term, valley, is advisable.

A peculiar feature of the Salt River fan is that several partly buried mounts and knobs raise their heads through it. One of them is the small Tempe Butte, close to the river a few miles below its exit from the mountain country; it is said to have been named by an imaginative English remittance man, who fancied that he saw from its top a prospect that resembled its classical patronymic. Another and much larger emergent mass is Dromedary Mountain, a ridge of red sandstone, whose imitative head-knob and back-hump are pointed out to every visitor for deserved admiration. Largest and farthest forward is the low Salt River Mountain group, apparently an uplifted and dissected fault block; and beyond it, in the trough between that group and the longer Estrella fault block, flows the slender Gila River. Salt River now makes its junction with the Gila northwest of the emergent mountains, but in the past it has sometimes joined the Gila on their southern side. Thus it repeats on a small-scale, inland fashion, the shifting behavior of the great Hwang-ho, in almost tenfold larger relation to the coastal mountain mass of Shantung in China.

Salt River at present trenches a shallow valley in its fan for about four miles below the fan head at the border of the broad mountain belt from which it issues; hence the Granite Reef distribution dam has been built on a rock ledge at the mountain base line, so as to raise the water to a level from which it may be led in canals, with a gradient of about

18 inches to a mile, out upon the fan surface either side of the apex trench. Other canals then branch off on several fan radii as they are extended. Farther on, low locks are provided to check the canal flow. Innumerable ditches carry water to the fields, all of which, as well as the roads between them, are laid out in squares on the lines of the National Land Office Survey. The natural washing of the fan by local rains as well as by mountain floods has provided so smoothly and gently sloping a surface that no regrading is necessary when the canal water reaches the fields. The field ditches usually run along plow furrows parallel to the field sides, but the more careful farmers plow their fields obliquely, on just such a gradient as is suited for their special crops. Water distribution is regulated by an official ditch-man or *zanjero*, a name that, like many others in the Southwest, records the earlier time of Spanish-Mexican occupation. A water supply for the farther fields is secured in part by pumping up the excess of underflow from the fields nearer the fan apex; and the pumps are driven by wire from an electric power plant at the main dam, which, when the reservoir there is full enough, also supplies power to Phoenix and several smaller cities as well as to a number of mining towns in the mountains.

Favorable as are the natural conditions here provided for irrigation, it is by no means the case that every arriving farmer has made a success of his enterprise. "Lungers" from Eastern cities seem sometimes to have thought they could suddenly transform themselves from office clerks into successful chicken ranchers; there are said to be a good number of ranches held by Phoenix banks on foreclosed mortgages. Yet on the whole so great a measure of profit has been reached that the water-users themselves have, on their own responsibility, added two new dams and are about to add a third between the Roosevelt and the Granite Reef dams, in order to provide extra storage for the rainfall of wet years which would otherwise overflow to the Gila and be wasted, and thus preserve so much of it as does not fly off by evaporation for local use in drier years. It is truly a delightful experience for the traveler, after he has crossed weary miles of dry country—where scattered range cattle are sometimes so near starvation in their search for spindly tufts of grass close under the stems of creosote bushes that they try to eat the spiny "cholla" and fill their muzzles with needle-like thorns—to come upon the verdant rectangles of the broad oasis and see compact herds of happier cattle pasturing up to their knees in alfalfa fields or resting, sated, in the shade of leafy cottonwoods. No wonder Arizonans are proud of the oasis; but I do wish they would not call it a "valley."

Some Great Basin Rivers Are Continuous

Condensed generalizations about a region so large as the Great Basin are dangerous if taken alone, but safer if diluted with exceptions. The first exception to be here introduced modifies the statements made above as to the discontinuity of the rivers in the dry country; but let it be noted that the very need of excepting the few long, through-flowing rivers from the many that run dry and fall short proves that river discontinuity is still the rule. The Colorado is, as already intimated, the chief exception, evidently because its headwaters are well fed by the rains and melted snows of the Rocky Mountains, and its valley, although heterogeneous, is almost as continuous as the river flow. But like the Nile and certain other rivers which, rising in wet regions, venture to cross deserts on their way to the sea, the Colorado is of diminishing volume in its lower course.

The slender Gila is next in order, with a length of about 400 miles. It rises in western New Mexico and crosses part of that state and all of Arizona on its way to join the Colorado; Yuma stands at the junction. Although thus succeeding, at least while high-water lasts, in reaching a trunk river that flows to the sea, the Gila is extremely variable in volume, being subject to rapid rise in "flash floods" and to almost as rapid fall. In dry seasons its volume varies irregularly along its course, according as inflow or evaporation takes the upper hand.

A third river of fair length is the Humboldt in northern Nevada, but it measures only 250 miles and its flow is even more variable and uncertain than that of the Gila. There is no fourth that need be mentioned here.

Valleys in Intermont Trough Plains

A second exception concerns the occurrence of valleys of erosion in aggraded troughs and basins. It not infrequently happens that the rock-bound valleys of Basin Ranges are continued by their intermittent streams for a short distance and with a small depth in the steeper, proximal slope of the piedmont fans, but the valleys usually vanish before the flatter distal slope is reached. It is much more rarely the case that the whole area of an intermont basin or trough in the Great Basin is dissected by the ramifying branches of an outflowing river, although such dissection is common in the Rocky Mountains, as has already been told. Among the not numerous cases of this kind are certain basins drained by the Gila, where it traverses the mountainous belt of Arizona between the plateau country of the northeast and the lower-lying and more desert country of the southwest. For although the lower course of this river avoids the difficult task of range-trenching by running around the mountains and keeping to the interweave of circummont aggraded trough plains, it most enterprisingly cuts deep canyons through a number of ranges in the upper half of its course; and there it is now well advanced in the work of carrying away the detritus from valleys eroded by its branches in the plains that occupied the inter-range troughs before the cross-canyons were cut so deep as they are now. This suggests that the river is, in spite of its slenderness, of antecedent origin, and that although compelled to aggrade the down-faulted troughs while faulting was in progress it succeeded in holding its course across the rising ranges. The fact that the trough filling is for the most part gravel and sand rather than fine silt shows that the troughs were not as a rule occupied by lakes.

A fine example of this kind, worthily studied and described by Ransome, is found in Dripping Spring "Valley," between the Mescal and the Dripping Spring fault-block ranges in southeastern Arizona.[34] When one sees the heavy limestones in which the Gila has cut its canyons up and down stream from this trough, one must marvel that so small a river could have mastered the uprising of blocks so massive and of rocks so resistant. The Coolidge Dam, lately completed, is built in the deep canyon of the Gila up stream from the trough through the great monocline of the Mescal Range.

The valley of the San Pedro, a north-flowing stream of very variable volume, which joins the Gila next down stream from its canyon at the south end of the Dripping Spring Range, is of somewhat different origin. The braided channel of its sandy wash lies a little below a flood plain with a width of about a mile, and the flood plain has been excavated, probably in consequence of a rather broad up-raising of the district (associated with the above-mentioned second

[34] F. L. Ransome, "Ray Geologic Folio," U. S. Geol. Survey, 1923.

upheaval of the Galiuro Mountains not far to the east), to depths of a few hundred feet, more or less, along the axis of a heavily aggraded intermont trough. In consequence of this excavation, the detrital slopes of the trough have been strongly dissected by the wet-weather streams that come down from the enclosing mountains. The San Pedro trough thus differs markedly from its neighbor, the Sulphur Springs trough, over the mountains to the east, which is as yet not at all dissected.

While the San Pedro trough was filling up, during and for a time after the most active faulting of the enclosing ranges, no longitudinal stream could have existed here, for the fine-textured deposits along the trough axis commonly contain lenses of gypsum, which imply the occurrence of many saline water sheets, separated by advancing fans, rather than of a continuous, north-sloping wash. Since then, and probably in consequence of a warping upheaval of later date as above suggested, the continuous longitudinal valley of to-day has been eroded and the trough slopes have been well dissected. The contrast between the dissected benchland of the trough sides and the true valley excavated beneath them along the trough axis is clearly recognizable, but both are included under the single name, San Pedro "Valley," by the few residents.

Worn-down Intermont Troughs

Although the plains which occupy the intermont troughs of the Great Basin ordinarily have every appearance of being built up or aggraded with detritus from the adjoining mountains, as above set forth, a certain number of them have been found to be not filled-up but worn-down plains, for their comparatively smooth surface bevels across the tilted edges of imperfectly consolidated gravels, sands and silts, as conventionally shown in the foreground of Fig. 6. The meaning of these worn-down plains appears to be essentially as follows. The broadly degraded prefaulting surface of the region—the Powell surface—appears to have been somewhat irregularly and perhaps repeatedly warped; whereupon degradation continuing on the up-warped areas supplied detritus which was strewn in stratified deposits over the down-warped areas, thereby forming what may be called "supernumerary beds." When the time for block-faulting came, these beds were tilted up with the underlying rock mass, thus giving a potential surface shown in the rigid background of Fig. 6, in which the inter-block trough angle stands above the level down to which erosion may there operate. In consequence of such displacement the weaker supernumerary beds have been rapidly reduced to a nearly plain surface; they now survive only in the low-lying "safe corner" of the inter-block angle, while the harder rocks, stripped of their weak cover and more or less dissected, still stand up boldly in dissected mountain ranges, as shown in the foreground of the same figure. In cases of this kind the trough-floor plain is not a surface of aggradation but of degradation. The number and distribution of degraded trough-floor plains is not yet known. They have been recognized by various observers; a recent account of a number of them has been given by Blackwelder.[35]

Piedmont Rock-floors or Pediments

A third exceptional feature of the Great Basin is found in certain broad, gently sloping rock floors or "pediments," which have been worn down by far-advanced arid degradation, as illustrated by the change from the potential background to the greatly reduced foreground of Fig. 7. When seen in distant

[35] Eliot Blackwelder, "Origin of the Desert Basins in the Southwestern United States," *Bull. Geol. Soc. Amer.*, 39: 262–263, 1928.

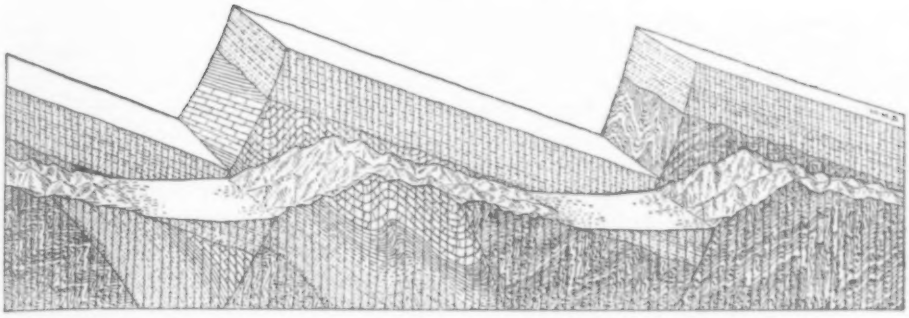


FIG. 6. DIAGRAM TO ILLUSTRATE THE ORIGIN OF WORN-DOWN, INTER-RANGE GRAVEL PLAINS

IN THE BACKGROUND, THREE UP-FAULTED "GILBERT" BLOCKS IN POTENTIAL (NON-ERODED) FORM, EACH BLOCK HAVING A HEAVY COVER OF LITTLE CONSOLIDATED GRAVELS AND SANDS UNCONFORMABLY OVERLYING THE "POWELL" SURFACE, PREVIOUSLY WORN DOWN ON THE RESISTANT AND DEFORMED ROCKS OF THE "KING" MOUNTAINS. IN THE FOREGROUND, THE SAME, REDUCED BY EROSION DURING AND AFTER FAULTING TO PRESENT FORMS, IN WHICH THE WEAK, COVERING BEDS ARE WORN DOWN TO INTER-RANGE PLAINS AND THE RESISTANT ROCKS ARE CARVED INTO MOUNTAIN RANGES.

profile, the almost rectilinear slope of these rock floors is surprisingly graceful and pleasing. All direct evidence of block faulting has disappeared from these residual mountains, and faulting is supposed to have taken place in their earlier history only because other less-consumed mountains in the same district are more manifestly of such origin. The worn-down, hard-rock pediments are comparable with the worn-down, intermont plains described in the preceding section; but the two kinds of worn-down plains differ in that those which are degraded on little consolidated detrital deposits may be associated with still vigorous ranges, while those degraded on the hard rocks of the ranges are, *ipso facto*, associated with subdued, dying-out ranges.

A particularly good example of a worn-down rock pediment is found

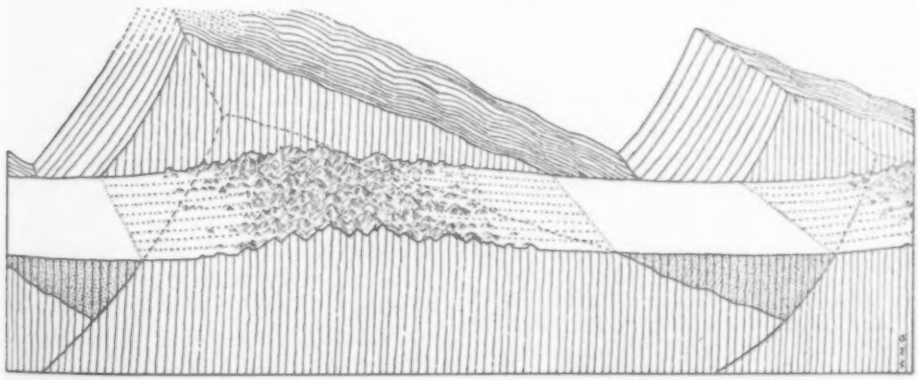


FIG. 7. DIAGRAM TO ILLUSTRATE THE ORIGIN OF WORN-DOWN ROCK FLOORS AROUND RESIDUAL MOUNTAINS

IN THE BACKGROUND, TWO UP-FAULTED BLOCKS IN THEIR POTENTIAL (NON-ERODED) FORM. IN THE FOREGROUND, THE INTER-BLOCK DEPRESSIONS ARE AGGRADED IN DETRITAL PLAINS AND THE UPLIFTED BLOCKS ARE GREATLY WORN DOWN TO SUBDUED MOUNTAINS, FLANKED BY SMOOTH ROCK FLOORS (PEDIMENTS) WHICH GRADE IMPERCEPTIBLY INTO THE DETRITAL PLAINS.

around the low Sacaton Mountains, some 40 miles south of Phoenix, Arizona. Here the dwindling mountains and their isolated outlying knobs appear to be greatly reduced remnants of a formerly larger and much higher mass, which was very likely of fault-block origin, like the still vigorous Estrella Range, a score of miles farther northwest. The Sacaton pediment has a forward slope measuring several miles in radial length, with a declivity of 4°, 3° or only 2°. It is variably veneered with sands and gravels. The existence of worn-down rock floors was made known by McGee, some forty years ago.[36] Further account of them was later given by Paige.[37] The fullest explanation of their origin is to be found in a masterly deductive analysis of the processes and products of arid erosion by Lawson[38] and an appreciative explanatory description of a number of typical examples has been prepared by Bryan.[39] A comparison of these greatly degraded and almost bare rock floors of greatly degraded mountains in desert regions with the soil-covered rock floors of greatly degraded highlands in humid regions is the subject of one of my own recent essays.[40]

Some Southwestern, circummont rock floors are a little dissected by shallow valleys, perhaps in consequence of a slight change in climate, but most of them are as valleyless as the detrital slopes and playas to which they gently slant down. Their valleyless condition is, however, of quite unlike origin from that of aggraded detrital slopes. On those slopes no valleys ever existed; during all their aggradation they have been traversed only by wet-weather stream channels or washes. But the development of the rock floors was begun by the erosion of true, rock-walled valleys in the original mountain mass, and it was completed by the consumption of the inter-valley rock-ridges until nothing but a rock plain was left. Such a plain might therefore be regarded as the last member of a series of forms all the earlier members of which are valleys in a young, mature or senile stage of evolution, but the last and most senile member of the series, being without enclosing slopes, falls out of the class of valleys and enters the class of plains.

Brief descriptions having now been given of the chief exceptional features which depart from the more prevalent forms of the Great Southwest, the lava plains of the Northwest must have brief mention.

The Lava Plains of the Northwest

Just as the formerly glaciated and now deglaciated region of the northeastern states has been excepted from the general statements made at the beginning of this essay regarding the mature continuity of valleys over the Atlantic two thirds of our country, so now an extensive lava-covered region which stretches to the north of the Great Basin almost as far as the international boundary must be excepted from most of the foregoing statements regarding the Pacific third of our country. There a preexistent land, probably of mountainous form, has been buried by volcanic outblowings of shattered lava or "ash" and by volcanic outpourings of molten lava to depths of hundreds or thousands of feet. The land surface very likely subsided slowly while the lava cover accumulated upon it. Ages must have elapsed during the growth of this heavy igneous shroud, for the petrified remains

[36] W J McGee, "Sheet-flood Erosion," *Bull. Geol. Soc. Amer.*, 8: 87–112, 1897.

[37] Sidney Paige, "Rock-cut Surfaces in the Desert Ranges," *Journ. Geol.*, 20: 442–450, 1912.

[38] A. C. Lawson, "Epigene Profiles of the Desert," *Univ. Calif. Geol. Bull.*, 9: 23–48, 1915.

[39] Kirk Bryan, ". . . The Papago Country, Arizona," U. S. Geol. Surv. Bull. 730, 1923.

[40] W. M. D., "Rock Floors in Arid and Humid Climates," *Journ. Geol.*, 1930.

of forest trees are found in various ash beds which alternate with the lava sheets. Longer ages must have elapsed since the later sheets were outspread, for part of the lava-shrouded region has been strongly deformed and its upraised lava cover has been worn down to low relief again. But in other parts the lava sheets are so recent that their surface, often retaining a ropy flow structure, banks against the adjoining mountain slopes just as the waters of a lake would do; hence the lavas when erupted must have been extremely liquid. Some well-preserved craters have been found in recent years.[41]

On the southwest the lava fields have been invaded by block faulting of the Basin Range type; the Warner Range, above described, is there situated; and to the southeast a broad dome has been elevated and dissected, forming the plateau-like Blue Mountains; but over a large area the post-eruptive deformation of the lava sheets has been of moderate measure. A consequence of the broad lava outpourings, taken in conjunction with the less arid climate of the Northwest than that of the Southwest, has been the erosion of normally continuous valleys by the rivers of the region. Of these the Columbia, entering in large volume from the mountains of western Canada, and its main branch, the Snake, heading in Yellowstone Park, are the longest. The continuous valleys of the Northwestern lava-covered country are therefore in strong contrast with the discontinuous valleys of the southwest.

A curious contrast is presented by the exceptional Northeastern and Northwestern regions. The Northeastern was temporarily covered, during a time of climatic chill, by a heavy, stratified, sluggishly mobile cover of whitish crystalline rock, familiarly known as ice, which was supplied by cold precipitation of water vapor from the higher atmosphere, and the ice cover severely scoured the surface over which it slowly crept outward from its Canadian centers of greatest accumulation until it disappeared by melting when the chilled climate warmed again. The Northwestern is more permanently occupied by a heavy, stratified, immobile cover of blackish crystalline rock, commonly known as lava, which was supplied by hot ascension from deep-lying subterranean reservoirs, and the frozen lava cover stands motionless while it is undergoing slow removal by weathering and streaming.

[41] W. T. Stearns, "'Craters of the Moon' in Idaho," *Geogr. Journ.* (London), 71: 43–49, 1928. Many features of the lava plains have been admirably described by I. C. Russell in several publications of the U. S. Geological Survey: Fourth Ann. Rept., 1884, 431–464; Bulletins 199, 1902; 217, 1903; 252, 1905; Water-supply Papers, 4, 1897; 78, 1903.

The Call of the Desert

Let no one imagine that the usual shortstopping of the valleys in our Western mountain ranges and, in consequence thereof, the prevailing absence of valleys from our Western intermont plains, to which repeated emphasis has been given in the preceding pages, should be regarded as in any sense physiographic defects. They are simply facts of occurrence or of non-occurrence, and are quite as normal and proper in their actively and irregularly disturbed arid region as valley continuity in the equable and humid East. The facts regarding the valleyless plains are peculiar and deserve to be remarked upon, but the remarks are not to be taken as in the least fault-finding. I would as soon censure the earth for running along its orbit more slowly in July than in January as complain of our basin plains because they are for the most part valleyless. Furthermore, while the desert nature of the greater part of the Southwest has also been insisted upon, it must also be insisted that the desert region is by no means utterly barren and worthless.

In the first place, the mountains of the desert rise into a cooler and moister climate than that of the plains around their base, and the mountains are coming to be used as summer resorts to a degree that may surprise many an Easterner, who hardly imagines the West to be so far advanced as to take time off for summer vacations. In the second place, many of the mountains have yielded and are still yielding metallic ore of enormous value. In the third place, although the greater part of the desert must remain desert, it contains many irrigated oases which have an attraction, indeed, a charm all their own, and their charm is coming to be more and more recognized by traveling Easterners. This is particularly true in recent years, since the great extension of improved highway construction has made cross-country travel in one's own car so enjoyable, and since due preparation for the reception of visitors has been made in so many of the oases. Even the residents in the desert towns themselves seem now to be less afraid than they used to be of calling the surrounding empty spaces by their proper name of desert, and they would do well to go one step farther and adopt the contrasted name of oasis for the desert towns, because that name has a much more alluring connotation than "settlement."

But it is to the call of the empty and valleyless desert plains themselves that this closing section of my story is to be devoted. In earlier times, when the desert dominated man, it was terrible, but now that man so largely dominates the desert it becomes a region full of entertaining wonders. It supports, except in the stream-swept washes and on the playa flats, a varied, open-spaced vegetation of unusual interest, from the long-lived giant cactus and the fantastic Joshua tree, to the little annuals that hasten to flower after the spring rains. A visit to the dry country in that season is to be warmly recommended, even if the descriptions of the "desert in bloom" are usually overcolored. The unexaggerated facts are good enough, although they are more difficult to set forth in truthful positives than in extravagant superlatives.

To see the facts rightly one must look closely and patiently. Among the flowers to be sought for is a minute, daisy-like composite, which is to my inexpert eyes more remarkable than the showy crimson cactus blossoms. Its stem rises less than an inch from the bare ground; its short roots are tender little fibers; its flower, although perfectly formed, is hardly more than a quarter of an inch in diameter and its seeds must be microscopic; yet, lying on or very close to the surface of the dry soil, they manage to preserve a spark of vitality through the parching heat of a whole summer of torrid Arizona noons to say nothing of the occasional freezes of winter nights, so that when the spring rains come again they germinate, grow up and down and blossom, complete in every little part, and thus pass on the spark of life to another year. If a despairing prisoner ever, as "Picciola" tells, gathered hope from the single flower that sprouted from a crevice in his prison wall, how many million hopes may the traveler on the desert gather from these indomitable little entities which so dutifully perform their life work under conditions apparently so adverse!

To one brought up in the geologically tame and climatically humid East, it is like reincarnation in another world to spend his later years in the geologically wild and climatically arid West. A new set of generalizations has to be made, to do justice to the new and strange environment; and at first it is difficult not to regard the new set as in a certain sense abnormal, because they are so unlike the long-familiar old set. But here the philosophy of relativity supplements the philosophy of evolution and helps

one to see that the new set of generalizations differs from the old no more than the old set differs from the new. It would be a confession of provincial-mindedness to think otherwise. The miniature daisy-like composite of the Western deserts is just as "normal" as the larger daisy of the Eastern pastures. The 15,000 feet of Pliocene strata near Santa Barbara on the Pacific coast, tilted up, overriden by Eocene strata and greatly eroded in Pleistocene time, are just as "normal," although shockingly surprising to an Easterner, as the much less thickness of undeformed Pliocene on the Atlantic coast. The occurrence of discontinuous mountain valleys and of valleyless plains in the West is just as "normal" in their geologically active and climatically arid region as is the prevalence of continuous valleys across mountains and plains alike in the geologically quiescent and climatically humid East. It is the contrast between the two, not the abnormality of either, that deserves emphasis, and I hope that this long story may help to make the contrast better known. But let me confess, in closing, that in spite of the repeated protests I have made here and elsewhere against the misuse of the old term valley as a name for a plain, I have no expectation that San Luis "Valley," Cache "Valley," the Great "Valley" of California or Salt River "Valley" in Arizona will ever be called "plains," as they physiographically should be, by the people who live on them.

LIGHT AND MEDICINES

By Dr. H. V. ARNY

COLLEGE OF PHARMACY OF COLUMBIA UNIVERSITY

HAVE you ever received from the druggist a colorless liquid prescription, which, within a week or so, became pink or green or yellow? Have you ever purchased a golden-yellow ointment to find that within a month or so it darkened to a nondescript gray? Have you ever noted that a bottle of perfume, delightful upon opening, became less agreeable and changed color as well as the months rolled around?

All these phenomena are occurring every day, causing annoyance to manufacturers and worry to pharmaceutical dispensers, who have to explain to irate customers why a colorless apomorphine solution turns green within twenty-four hours and why a mixture containing phenol is apt to turn pink.

The manufacturers and the dispenser desire to furnish the consuming public with the best medicaments available. They purchase the choicest materials, they compound them with the utmost skill, they assay the finished product and thus standardize it to a definite strength, and then after all these precautions have been taken they sometimes find to their disgust and to their financial loss that the perfect product they evolve becomes imperfect through no fault of their own; becomes deteriorated (even when bottled in a sterile glass container) by action of some outside factor over which they have no control. These deteriorating factors are of several types. In some cases the action of air produces changes just as the action of moist air is responsible for the rusting of iron. In some cases the type of glass of which the bottle is made may be the mischievous factor. And in many cases the action of daylight is responsible for the change, just as daylight, and especially sunshine, fades the color of the wall-paper of our rooms.

And so we have a considerable list of what we call light-sensitive chemicals and other medicaments, the United States Pharmacopœia and the National Formulary (our two national standard authorities for the quality of drugs and medicines) listing no less than 423 medicaments that should be protected from light. These light changes are mischievous where medicines are involved. On the other hand, there are instances where carefully controlled light changes are beneficent gifts of nature to man. Thus, as aptly said by a former president of the American Chemical Society, a vast industry is based upon a single chemical reaction produced by the action of light, the darkening of silver salts when exposed to light being the foundation of photography and all that photography now implies.

The mischievous effect of light on medicaments is more annoying than serious. It is true that when white crystals of santonin (that vermifuge obtained from Turkistan wormseed) turns yellow, the decomposed product has been known to produce dangerously irritating effects. In most cases, however, the deterioration either lessens the medicinal value of the product or is annoying either from the psychological or esthetic standpoint. A colorless liquid medicine that turns green overnight is apt to alarm a crochety patient. A colorless solution that deposits a dark coating upon the walls of the bottle is not beautiful to behold. Hence both manufacturers and retail pharmacists endeavor to

lessen such light changes in the medicines they produce or dispense. This explains the use of blue or amber glass bottles. This is the reason why careful pharmacists dispense "eye drops" in bottles enclosed in opaque cardboard cartons. This is why the labels on bottles of certain staple chemicals bear the caution, "Store in a dark, cool place."

For fifty years or more pharmaceutical and chemical investigators have been endeavoring to solve the riddle of deterioration of chemicals under influence of light. These researches have been directed (*a*) as to the chemical effects of such deterioration and (*b*) as to means of preventing such deterioration. A mass of literature on these topics is available but, as an eminent Dutch investigator has written the author, this material "was not of value save in this respect—that I learned from it how it had not to be done."

Since the introduction of biological medicaments—sera, vaccines and glandular products—the problem of light changes has become distinctly acute, as these medicaments are very sensitive to light and a deteriorated specimen is sometimes worse than inert; it may even be harmful to the patient.

In a discussion of this topic at the 1926 meeting of the American Pharmaceutical Association it was decided to appoint a committee to study the problem of light-sensitive medicines, and after a two-year preliminary survey, the findings of the survey indicated the need of definite research on the problem. As these findings have been published elsewhere,[1] it only need be stated at this time that inquiry among pharmacists, chemists, physicists and glass manufacturers showed little practical knowledge of the problems, the only worth-while work having been performed by the physicists of the Bureau of Standards and by two foreign investigators, Dr. J. Eisenbrand, of Germany,[2] and Dr. J. B. M. Coebergh, of Holland.[3]

Armed with these facts the present writer, in May, 1928, called a conference which was attended by representatives of the American Pharmaceutical Association, of two associations of pharmaceutical manufacturers and of the association of bottle manufacturers. After discussion lasting throughout the day, it was decided that definite research along practical lines should be carried out, and the present writer was authorized to appoint a committee to raise funds for such a research. This fund-raising campaign was carried out last year and a $2,000-research fellowship was provided for, eighteen subscriptions for $100 each being secured from pharmaceutical and chemical manufacturers, while the remaining $200 necessary to complete the fund was obtained from the Research Fund of the American Pharmaceutical Association.

The $2,000 being secured and turned over to a trustee, the writer secured as his research assistant Mr. Abraham Steinberg, a graduate student of the College of Pharmacy of Columbia University, and these two with the cooperation of Abraham Taub, professor of physics at the same institution, are now engaged in the research which may be outlined as follows.

With the fine cooperation of chemical and pharmaceutical manufacturers and of the manufacturers of glass bottles the necessary chemicals and pharmaceuticals and the appropriate containers have been secured.

The medicinal substances undergoing tests are of such varied character as sweet spirits of niter, bleaching powder and apomorphine, the only point of resemblance being that all are known to be sensitive to light. These samples (thirty-six in number) have been placed

[1] *Jl. Am. Pharm. Assoc.*, 17: 1056, 1928.

[2] *Pharm. Ztg.*, 72: 247 and 1275, 1927.

[3] Inaugural dissertation, 1920.

in pyrex tubes, and these well-corked, wax-sealed tubes are in turn placed in the glass container that is being tested. The pyrex tubes (obtained through the courtesy of the Corning Glass Works) are used as the real container since that type of glass is less apt to affect the chemical stored therein than an ordinary glass bottle. The outer container actually under test is at the present time limited to seven kinds of bottles: (*a*) three types of green, (*b*) one type of blue, (*c*) two types of amber, (*d*) one type of flint, or colorless. The spectrophotometric reading of each of these seven types of glass containers has been recorded, thus fixing the color transmission of the glass in question. It is interesting to note that such spectrophotometric reading of a number of the batches of bottles received from the several manufacturers cooperating in the research shows a distinct uniformity in color of their respective stocks, especially where amber and flint glass are concerned.

We are at present subjecting more than two thousand specimens to the action of sunlight. One set of three hundred specimens is kept indoors on shelves near a window, thus matching conditions found in the average stock room. This set examined month by month in their sealed pyrex tubes will be kept a year before the containers are opened. The remainder of the present batch of specimens (numbering 1,700 items in all) are fastened on panels each protected by a sash of glass, these specimens being exposed on a roof to the effects of unimpeded daylight. One batch of samples is being exposed for one month, and this batch will soon be taken in and examined as to the effect of one month of winter daylight. A corresponding batch of the same chemicals and the same type of containers will be left on the roof for one year, thus subjecting these medicinals to both winter and summer daylight. Those medicaments which our tests show survive exposure for one month will be bottled and exposed two, four and six months respectively. Incidentally, we plan to repeat the one-month experiment during the summer, thus having a comparison between the effect of winter daylight and summer daylight.

Each of the medicaments that we are studying has been examined chemically and physically and has been found to comply with the requirements set forth by the United States Pharmacopœia. The surplus stock (in their original containers) are stored in our dark room and will be examined from time to time in order to detect deterioration due to causes other than exposure to light.

As to batches of medicaments which are brought in after exposure to one, two, four, six and twelve months of daylight, they will again be examined as per tests of the pharmacopœia as to strength, purity and physical appearance. Some of the chemicals exposed show deterioration (color change, etc.) after only a few days of exposure. In other cases the change is more subtle. In ether, for example, decomposition is shown by the appearance of peroxides, and the special chemical test provided by the pharmacopœia will indicate such change to us. In other cases, such as Labarraque's solution, deterioration will be indicated by a loss of strength of the essential component, thus giving an exact measurement of the deterioration month by month.

"What's the use of all this work?" may be the query of the casual reader. In the first place there is apparently no authentic record of the relative value of colored glass containers in preventing the deterioration of chemicals under the influence of light. In a general way we have learned by empiric methods that clear glass bottles are not good containers for light-sensitive chemicals; we

think that amber bottles are the best containers for such chemicals and that blue bottles are the worst, but these opinions are based largely on guess-work. Coebergh, by the use of light rays of known wave-length, found that different chemicals have different sensitivities to different light rays. We are acting upon the Coebergh findings by applying his idea to the medicaments stored in the bottles themselves. By this method we hope to tell manufacturers of pharmaceuticals, of chemicals and of bottles exactly what type of bottle is best suited for the storage of each chemical studied. We hope to give definite opinions as to whether deterioration, wherever observed, is due to the action of light or whether some other factor, such as alkalinity of the glass container or the influence of the air, produces the undesired change. And lastly, we hope, in those cases where light is clearly proved to be the destructive factor, to discover in each case the appropriate "stabilizer," that appropriate chemical a trace of which may aid the medicament in resisting the untoward action of light rays.

THE NEWER HOMEOPATHY

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I

STONE AGE physical and chemical science pictures each and every material substance as a crystallized or condensed spirit, or spirit-fragment. The water in the domestic bowl, for example, is a conscious, intelligent, autonomous ghost-concentrate, constantly evaporating or dematerializing into invisible water-potentiality. This intangible potentiality fuses with and becomes an integral part of the great aqueous oversoul, general humidity. Through this atmospheric fusion the captive water broadcasts its pleasures, pains, friendships, enmities and motor impulses to near-by clouds, mists, lakes, rivers and oceans.

Taking advantage of this invisible atmospheric hook-up, Stone Age meteorologists attempt environmental water control. Artificial ripples in the domestic bowl, for example, might logically telegraph sufficient motor impulse to a near-by lake to overturn an enemy canoe. Sprinkled on the ground, the captive water might broadcast sufficient precipitation-impulse to cause general humidity to materialize in the form of rain. Thrown on hot stones, the tortured water sample conceivably radiates man-fear and evaporating impulse, sufficient at times to cause dematerialization of local clouds or mists.

Through a similar atmospheric hook-up with generalized ancestral tribal gas a tortured enemy logically telegraphs cowardice and bodily weakness to his distant tribal brethren. Pierced with thorns, the foot-prints of a lion relay lameness to the jungle cat. Milk, inadvertently spilled on fire, telegraphs intangible fire spirit to bovine udders, sufficient at times to cause cessation of milk flow, or even ulcerative lesions of the mammary glands.

II

Logical and consistent application of the same invisible telegraphy was probably the first system of medicine developed by our prehistoric ancestors. A fragment of snake skin, tortured by smoke, pulverized, swallowed, subsequently insulted by gastric juice and finally cast off from the human body, would logically broadcast man-fear, snake-cowardice and snake-attenuation to near-by serpents. Thus inductively cowed and weakened, local snakes would rarely bite man. Their telepathically attenuated venom would do little or no harm. A sample of a patient's ghost-consubstantiated blood, narcotized with plant juice, inductively narcotizes the invading consubstantiating ghost. Swallowed by the patient, the narcotized hemic ghost-fragment cries out in terror to the residual pathogenicity, initiating its deconsubstantiation. Tubercular sputum mixed with dry earth, then applied as cutaneous massage, telegraphs dryness and perspiration-attenuation to invading phthisis, primitive perspiration being an external gastric juice more powerful than any digestive ferment of modern science.

If a fragment of the invading pathogenicity can not be obtained for ceremonious torture, equally logical induction therapy is possible through imitation, or double-relay magic. An image of a tiger is constantly evaporating into invisible synthetic semi-tiger potentiality, which mingles with and

partially fuses with the real atmospheric tiger spirit. Ceremonious torture of the image, therefore, is relayed to the great tiger oversoul and, through this oversoul, transmitted to the jungle enemy. By the same logic, an image of an invading pathogenic ghost, narcotized, insulted, mutilated and swallowed, relays terror and attenuation to the real pathogenicity. A ceremoniously tortured smallpox image inductively terrorizes environmental smallpox. Or, clothed in rich robes, praised, flattered, fed with sacrificial meats, it relays pseudo-friendship to the environmental virus, sufficient at times to change this invisible anthropophagus into a loyal servant of the local tribe.

III

With the development of later social organizations Stone Age therapeutic magic was changed to a real homeopathy. With the union of families into clans, tribes and nations, similar group organizations were conceived to take place in the pathogenic world. Each virus-group was usually dominated by some particularly virulent organ-eating or symptom-producing ghost. It was no longer necessary to procure a sample or to prepare an image of an individual virus. Any member of the symptom-specific group could be captured or imitated. Through ceremonious torture of this group representative, attenuation and terror could be relayed. A real inductive *similia similibus curantur*. Baldness, for example, could be inductively weakened or scared away by a swallowed gastro-intestinally insulted fragment of frog skin, an easily attainable consubstantiated anti-hairiness potentiality. Excreta from any form of diarrhea could be tortured and applied as cutaneous massage, relaying through the bellyophagic clan-organization attenuation and man-fear to invading gallstones, appendicitis, cholera, typhoid fever and other abdominal pains.

This early pagan *similia similibus curantur* did not reach its *reductio ad absurdum* till all pathogenicities were enrolled under the captaincy of the medieval unitarian Satan. Formal burning of a Satan-consubstantiated witch, the eating of roast or fire-attenuated witch flesh and the torture of an imitation Satan in the bull ring thus became the major official method of disease control.

IV

With the development of nineteenth century Christianity, however, not only did this unitarian antisatanotherapy become obsolete, but all earlier forms of therapeutic magic became equally illogical. Autonomous or group-motivated spirits were no longer conceived to control pathogenic viruses.

In spite of this theological discard, however, the essential technique of early pagan *similia similibus curantur* was retained and justified by new hypotheses drawn from material science. Our Stone Age ancestors postulated that, in addition to magically induced cowardice and attenuation in an invading pathogenicity, the swallowed or cutaneously applied, ceremoniously attenuated virus-sample systematically exercises and increases the consubstantiation-resistance of the human body. Swallowed snake skin, for example, was a logical Stone Age vaccine, whose easy conquest and expulsion from the body strengthens and encourages the normal human anti-snake potentiality. Fecal massage is a Stone Age cutaneous vaccine, systematically training the human gut for war against visible and invisible fecophilic viruses.

This retention and metamorphosis of theologically discredited pagan homeopathic magic into a modern physiological science is usually attributed to Hahnemann. The Hahnemann physiological theory assumed that, given in small, readily conquered doses, any

symptom-producing material is a symptom-specific vaccine, training and increasing physiological symptom-specific resistance. A headache-producing drug is a postulated logical therapeutic vaccine against all forms of headaches. Morphine logically immunizes against insomnia. Alcohol trains and strengthens locomotor-ataxia-resistance.

V

The Hahnemann renaissance of early pagan homeopathic technique under this new rational was, of course, not without its critics. Nineteenth century medicine had become so skeptical of metaphysical deductions as to demand convincing experimental and clinical proof. Very suggestive evidence was soon quoted by Hahnemann—the therapeutic vaccine, nitroglycerine. Given in toxic doses nitroglyycerine produces a most excruciating headache. According to Hahnemann immunology, therefore, oral administration of minute, easily licked doses of nitroglycerine should increase headache-resistance. Hahnemann pointed with pride to the fact that patients suffering from headache are at times almost miraculously cured by such administration.

This observation was probably the most important single research stimulus of the nineteenth century. At the time it was made, biologists knew nothing of the physiological action of nitroglycerine, and only the most fragmentary physiology of any currently used empirical remedy. Pro-Hahnemann and Anti-Hahnemann controversies, therefore, were pure metaphysics. It was not till the closing decades of the nineteenth century that physiology was prepared to present scientific evidence.

By this time impartial non-clinical research had shown that nitroglycerine belongs to a relatively large group of toxic agents, producing as its most easily demonstrated physiological effect a lowering of arterial blood pressure. Clinicians had long noted that there are different types of headache—one type, for example, associated with abnormally high blood pressure, a second type characterized by subnormal arterial pressure. Impartial clinical tests now showed that nitroglycerine given to a patient with high-blood-pressure headache at times restored blood pressure to normal, often accompanied by cessation of painful symptoms. Given to a low-blood-pressure headache, however, nitroglycerine was found to further decrease blood pressure, invariably magnifying the distressing symptoms. Nitroglycerine, therefore, was not the symptom-specific vaccine Hahnemann assumed. Moreover, there was no evidence that this toxic substance had any immunizing power whatsoever. Given in repeated minute doses to laboratory animals nitroglycerine stimulated the development of no increased resistance or supertolerance even to nitroglycerine itself.

Similar impartial laboratory and clinical studies failed to demonstrate the postulated immunizing powers for such common drugs as quinine, iron, mercury, strychnine, caffeine, digitalis and pilocarpine. Fully 98 per cent. of nineteenth century empirical pharmacology was thus shown to be in non-conformity with Hahnemann immunology. Hahnemannism at most could be but 2 per cent. clinically true.

VI

A few of the less common therapeutic agents of mid-Victorian empiricism, however, and many agents subsequently introduced were found to stimulate the development of a remarkable tolerance, sufficient at times to protect man or laboratory animals against many hundred times the usual lethal dose of a toxic agent. Among the commoner agents thus found in apparent conformity with Hahnemann immunology are

numerous zootoxines (*e.g.*, snake-venom), numerous plant extractives (*e.g.*, mushroom poison), and almost any toxic or non-toxic substances of microbic origin. Scientific homeopathy, therefore, was forced to turn its sole attention to these few apparent confirmations of the Hahnemann postulates.

These apparent confirmations of Hahnemann immunology, however, were soon found not to confirm his major belief. Immunization with subtoxic doses of cobra venom, for example, while demonstrably increasing cobra-resistance, was found to give little or no increased protection against other zootoxins, and no protection whatsoever against other toxic agents producing the same or similar symptoms. With very rare exceptions the immunity following vaccination with any morbidic agent was demonstrated to be highly specific for that agent.

VII

Furthermore, even the few successful specific immunizations were soon shown to be effected by a physiological mechanism not dreamed of by symptom-specific immunology. Normal laboratory animals, for example, injected with moderate doses of cobra venom, usually die as a result of cardiac paralysis. An excised normal animal heart, kept alive under artificial circulation, usually ceases to beat from two or ten minutes after a milligram of cobra venom is added to the circulating fluid. The heart of a cobra-immune animal is equally susceptible. Cobra immunity, therefore, can not be explained on Hahnemann assumption of increased organ or symptom resistance.

Still further limitations of Hahnemann homeopathy were soon found necessary, proof of error in the postulated belief that minuteness of dose favors immunization. The exact opposite was at times demonstrated to be true. Injection with too small a dose of a successful immunizing agent occasionally leads to the development of the exact opposite of an acquired immunity, causing an acquired hypersusceptibility. Vaccination of certain laboratory animals with too small a dose of egg-white, for example, may stimulate the development of a specific idiosyncrasy to egg albumen. Subsequent feeding or injection with egg-white may throw the specifically hypersensitive animal into fatal convulsions, or lethal shock. The newer scientific immunology, therefore, was forced to limit itself to the relatively few immunizing agents with which immunization is possible without risk of stimulating the development of the distressing and often dangerous opposite effect.

VIII

Thus limited, stripped of every vestige of its original *similia similibus curantur*, given a new nomenclature and an entirely new physiology, the ½ per cent. residual fragment of Hahnemann homeopathy is to-day endorsed by and is an integral part of scientific medicine.

The evolution of this newer circumscribed scientific homeopathy epitomized medical history. Conceived by Stone Age wizards as a logical magic against individual pathogenic ghosts, raised to a theological *similia similibus curantur* by later paganisms, discarded as pagan superstition by modern Christianity, its essential technique rescued from this discard by nineteenth century adolescent material science, robbed of 99½ per cent. of its assumed physiological rational by later experimental and clinical research, its residual ½ per cent. verifiable biological truth is to-day officially endorsed by conservative clinical science.

The next step, of course, will be a modification of existing legislation in conformity with this evolution.

THE PHYSICAL NAPOLEON

By Dr. JAMES FREDERICK ROGERS

THE U. S. OFFICE OF EDUCATION

THE rise or the fall of a great man, aside from the combination of external circumstances which may make or destroy him, is largely influenced by his physical condition. Of no man is this more evident than of Napoleon, whose physical powers were as marvelous as his mental accomplishment, and the waxing and waning of whose star, while far from being wholly determined by, was significantly coincident with, his bodily development and decline.

Napoleon's father, who is described as slight, lithe and handsome in face and figure, and full of energy, died at the age of thirty-nine of cancer of the stomach. It was from his mother, however, that the illustrious son seems to have derived his unparalleled physical powers. She is said to have been a remarkably forceful and courageous woman, of heroic mold and of great beauty, which she retained to advanced age. She shared with her husband the hardships and perils of the Corsican struggle against the French, and it was while she was following the fortunes of Paoli's patriots in one of their expeditions that Napoleon was born.

As a child Napoleon was "turbulent, active and lively in the extreme," and in such an atmosphere of national strife it was but natural that his favorite playthings should be a sword, drum and toy soldiers. He was sent to school at six, and on his way he is said, by tradition, to have regularly exchanged his own piece of white bread with a soldier on duty for a bit of the coarse army loaf. He was teased at school for his devotion to one of the little girls and for walking up and down absorbed in thought, with his stockings falling over his heels. He made furious return for such treatment. He feared no one, and no numbers. He said of himself later, "I struck one, I scratched another, and I was a terror to everybody."

At school in Brienne at the age of ten he held himself aloof from the other boys. He played little and took long walks alone. The pupils were lodged with Spartan plainness in dormitory rooms six feet square. They were served amply with four meals a day—breakfast and luncheon of bread, water and fruit; dinner of soup, meat, a side dish and dessert, and for supper a joint with salad or dessert. With the latter meal a weak mixture of wine and water, known in sarcastic school phrase as "abundance," was served.

Each boy was assigned a small garden plot to cultivate. Napoleon fenced his about with a hedge, fiercely drove out all intruders and spent his leisure here in reading all the books he could find. Though for a long time at odds with his school fellows, his fearlessness of them and his indifference to punishment meted out to him by his teachers won their esteem. They ceased to tease the Corsican, and he, in turn, grew more friendly and entered more frequently into their sports. On one occasion he marshaled his fellows in a mimic war with snowballs and is said to have planned and directed with remarkable skill the building of elaborate snow forts. Among other accomplishments, dancing was taught, and on one occasion Napoleon was one of seventeen who rendered a country dance at a public exhibition. At the age of fourteen he was described in the official report as being of good constitution and in excellent health.

In the next year he was sent to the fine military school in Paris, where, he says, "we were fed and served splendidly." There were also severe discipline and hard work. Lessons lasted two hours for each subject, and there were four subjects each day, except on Thursday and Sunday. The students had military drill every day and on Thursdays and Sundays were taught firing. There were excellent teachers of fencing, dancing and riding, but Napoleon excelled in none of these accomplishments, and, in fact, slighted them, preferring to spend all available time over his books.

At sixteen he was removed from Paris to the artillery regiment of La Fère, one of the best in the army, where, under splendid discipline, three days a week were devoted to theory and three to artillery practice. He took private lessons in dancing and deportment which he had neglected at the Paris school, but he failed to acquire an easy or polished manner.

Although his routine work was arduous, he added to it by his studies and often labored from twelve to fifteen hours a day. At eighteen he contracted a fever, probably malarial, which affected his health to some extent and served as an excuse for furloughs to Corsica. His complaints of ill health continued, and at twenty-three he is described as small, thin and looking spectral and uncanny, with pallid cheeks and dark rings about his eyes.

Two years later at the siege of Toulon he was still remarkable for his extreme thinness and the almost yellow tint of his visage. He was, however, abounding in energy, as evidenced by his work and his "two eyes, sparkling with keenness and will power." He won high praise by his tireless activity and his exhibition of "much science, as much intelligence, and too much bravery." At Toulon Napoleon contracted a troublesome skin disease, probably the "itch," which, from neglect, remained with him until he became consul, and it did not add to the attractiveness of his person. Only the flash of his eyes, those wonderful eyes, gave indication of the tremendous physical energy stored within that slender body.

In 1797, at the age of twenty-eight and in command of the revolutionary armies, he was still very thin, "of sickly hue" and "covered with tetter," but Talleyrand saw in him a "charming figure . . . with a pale complexion, and a certain tired look." The look of fatigue was deceiving, for he was capable of vehement and tireless activity, quite equal to his imagination which was already soaring toward oriental conquest and world empire.

On his return from Egypt he was "very meagre and very yellow, his complexion coppery, his eyes sunken, his shape perfect, though rather slender. . . . His eyes were a beautiful blue, which depicted in an incredible manner the different emotions which agitated him . . . his teeth without being very regular were very white and very good and there was perfect regularity and beauty in all his features. He was five feet six inches in height . . . his neck was rather short and his chest large."

He was, as he said, made for work, and with the colossal enterprises he now conceived and their successful working out he expanded bodily. By the end of the consulate, in 1804, at the age of thirty-five his figure had rounded to a fulness which indicated both mental satisfaction and abounding health and vigor of body. It is in this period that Napoleon's activities reached their climax, and there was a coincident culmination of his physical perfection. Such power for work has never been possessed by any man of whom we have knowledge. "I am conscious," he said, "of no limit to the work I can get through." For both mental and physi-

cal exertion he seems to have been at this time incapable of fatigue. "It would require constitutions of iron," wrote one of his ministers in 1803, "to go through what we do. After a day's ride in a carriage we no sooner alight than we mount on horseback and sometimes remain in our saddles for ten or twelve hours successively." In one battle he went for five consecutive days without sleep and without removing his boots, and he was fully recovered after a sleep of thirty-six hours. In dictating to his secretaries he would walk to and fro for as much as six hours without apparently being conscious of his pedestrianism. He exhausted all his subordinates. His councils of state often lasted eight or ten hours at a stretch. Once at two in the morning when the ministers were all worn out and one had even succumbed to sleep, Napoleon stirred them to further deliberation: "Come, gentlemen," he said to them, "Pull yourselves together, it is only two o'clock . . . we must earn the money the nation gives us." "He could work for eighteen hours at a stretch at one subject or many." "Never," says Roederer, "have I seen his mind weary; never have I seen his mind without spring; not in strain of body, or wrath, or the most violent exercise." Even his enemies declared that his capacity for work was beyond compare and equal at least to four men in one.

While he slept from six to eight hours in the twenty-four, when aroused at any moment of his slumber he was in perfect possession of his mental powers, and could sleep again at will. If compelled to go long periods without sleep, he always made up for the loss. After times of great fatigue "he condemned himself to twenty-four hours of absolute rest," and on one occasion he slept for thirty-six hours.

When at home he arose at about seven. He spent much time over his toilet, for he was exceedingly careful of the cleanliness of his person. He was very careful of his teeth, which he kept in beautiful condition. He had brought from the East the habit of having himself massaged, and the more vigorously he was rubbed the better he liked it. "Harder!" he would say to his valet, "harder! as though you were rubbing an ass!" His bath was completed with a sprinkling of Cologne water of which he was very fond.

He gave very little thought to his eating. He ate very hurriedly, spending only from seven to a dozen minutes at the table. He preferred plain dishes and was especially fond of fricasseed chicken. Red mullet, roast mutton, beans, lentils and macaroni with Parmesan cheese were also favorite dishes. Of roast meats he ate the "brownest" part and had a horror of meat underdone. He rarely drank anything but a half bottle of Chambertin wine at meals, diluted with water. After breakfast and dinner he took one cup of strong coffee. Besides his three meals he often had chocolate or ices, of which he was very fond, served in the midst of his work. He never complained of what was set before him, and sometimes in his abstraction he was not aware that he had dined. His digestive organs occasionally rebelled against his hasty eating, and, recognizing that they knew what they were about, he, by way of cure, ceased eating, drank copiously of barley water and took vigorous exercise, riding horseback at high speed for twenty or thirty miles.

The notion that Napoleon was subject on a few occasions to epileptic fits seems to have arisen from the secrecy maintained by his suite over sudden and prostrating attacks of indigestion.

He found his chief pleasure in work, but "air and exercise were necessary to his existence, and the privation of them, from rain or any other cause, made him

not only disagreeable but really ill." He entered into sports with boyish glee. The favorite game of his suite during the happy days of the consulate was prisoner's base. Napoleon was not very agile, and in running often fell down, but he picked himself up again with shouts of laughter.

He used a great deal of snuff, but only by bringing it to his nose, smelling it and letting it fall from his fingers. "Smoking," in his opinion, "was good for nothing but to entertain idlers."

His senses were exceedingly keen; the slightest bad odor was sufficient to upset him greatly; the smell of paint made him sick. He was fond of the perfume of aloe wood and used cologne constantly, but some perfumes were intolerable to him. He was very sensitive to cold; he often had a fire on the hearth in July, and, except in the hottest weather, he had his bed warmed. He had a horror of impure air, and he turned pale at the remembrance of blood covering his hand from a wound on a friend. When with the army, all this keen sensibility was suppressed and he could stand more of the painful and disagreeable than any common soldier. In the field he went to sleep at seven and began his tireless labors again at one in the morning.

He was always more or less nervous and irritable; he often bit his nails, and he had the habit, when absorbed in thought, of shrugging his right shoulder and at the same time moving his mouth from left to right.

While his enormous energy spent itself chiefly in work, it sometimes burst forth with volcanic fury; in one of these explosions he kicked over the table and smashed the china, and on another occasion he planted his foot with tremendous force against the abdomen of Senator Volney, much to that gentleman's discomfort. His pulse was slow, between fifty and fifty-five, and even in his fits of rage he seems to have been self-contained, as he never felt his heart beating and his valet noted that the blood never rushed to his face.

As emperor, Napoleon grew heavier in body, and his appearance was praised or ridiculed according to the attitude of the witness. Queen Louise admired his head as "that of a 'Caesar,'" but her lady in waiting, who was more sincere, said he was "excessively ugly, with a fat, swollen, sallow face; he was short, very corpulent and entirely without figure." He was becoming obese, but was otherwise the picture of health and strength. The keen, melancholy, fathomless eyes were as marvelously expressive as ever, and his voice was, even to his valet, "of such beautiful quality that, however softly he speaks, it goes to the very depths of the heart."

In 1807, in his thirty-eighth year, Napoleon wrote to his brother that his health was never so good. Percy, one of his surgeons, writing in this year said, "The Emperor is made of iron, soul and body, always on horseback, galloping about in all weathers, bivouacking, working like ten men, never ill, never tired." In September, 1809, Napoleon again speaks of his health as perfect in a letter to Josephine, and in this year he was capable of riding ninety miles on horseback, without stirrups, in five and a half hours, but in two later letters in that year he mentions being ill. In 1810 he speaks in his letters to her of his health as only "fairly good" or "pretty good." There was, from this time, a slow decline of his health and vitality, and with this, of his power for uninterrupted work.

There was no particular ailment which depressed him, but doubtless his growing obesity, against which his physician, Corvisart, had warned him, was at the bottom of it all, for it was by no means a sign of health. This condition indicated that he was eating more or taking

less exercise or both. Surrounded with every luxury, the emperor was not so ascetic as the first consul. He partook of pastries and fancy dishes as well as of plain foods, though it can not be said that he acted the epicure except, perhaps, on one or two occasions when he seems to have been at a loss for other means of passing his time. Judged by the standard of the times he was still temperate in both meats and drinks, though the standard was not the best.

He had some minor ailments, hemorrhoids and possibly bladder trouble, and for these he spent more and more time in hot baths. Neither the complaints nor their treatment conduced to bodily activity or to loss of fat.

His mind seemed about as active and tireless as ever. His ambition and imagination, in fact, outstripped all possibilities, and the failure of the Russian campaign was due more to attempting the impossible than to any physical lapse, though some critics find him wanting in old-time vigor and care for details. His way was certainly not so clear or so easy as in earlier campaigns, and he hesitated and sat idle where previously he had acted.

He had, at this time, become slow in all his movements. There was no sparkle in his eye and his expression was dull. "His lassitude was noticeable and when he roused himself it was often for trivialities." Nevertheless, this was merely a lapse from *Napoleonic*, and not ordinary powers, and on the retreat from Moscow "he shared for days the common hardships of his soldiers, and even marched for hours through snow and mud without showing signs of physical or nervous exhaustion."

In the Dresden campaign of the following year the signs of weakness were more marked. He favored his health, postponed operations on account of rain and "seemed beset with alternate lassitude and energy." At Düben he could not make up his mind, and sat for two days on a sofa with dispatches accumulating before him, engaged in drawing capital letters on sheets of paper. How far mental and emotional factors, not having to do with immediate events, distracted him at this time can never be sifted from the effects of purely physical condition.

Sir Neil Campbell, the English ambassador, said of him, during his imprisonment in Elba, "I have never seen a man with so much activity and restless perseverance: he appears to take pleasure in perpetual movement, and in seeing those who accompany him sink under fatigue." Nevertheless "he occasionally falls into a state of inactivity never known before, and sometimes reposes in his bedroom of late for several hours a day; takes exercise in a carriage and not on horseback. . . . During his ten months at Elba he became very stout and his cheeks puffy." Mollien, one of his cabinet ministers, noticed that at Elba "a kind of lassitude, never known before, took hold of him, after some hours of work."

The Waterloo campaign, the critics tell us, was planned with consummate brilliancy. On June 12 Napoleon rode in his landau seventy miles and "on the next day he got through an immense amount of work." On the fifteenth he was in the saddle for nearly eighteen hours, except for one short period of rest when he fell asleep. That night "he was overcome by fatigue" and the next day was still very weary and did not exert himself until two-thirty, when he rode through a time of terrible heat until night. On the morrow he again showed fatigue. Whatever conflicting mental and emotional states may have had to do with it, the physical Napoleon of Waterloo was not the physical Napoleon of Austerlitz. Nevertheless, he was still Napoleon, and Waterloo, despite the mistakes he may have made, came

well-nigh being a victory for the French, and had it been so, his exhibition of unusual fatigue would hardly have been recorded.

After the battle the defeated man was prostrated, body and soul. His resourcefulness, physical and mental, was for the moment in abeyance. The failure of his achievement to keep pace with his flights of imagination was more than he could bear, and he was aware that his opportunity to recover his place in the world was past.

As prisoner of the English, at the age of forty-six, he appeared to Captain Maitland a "remarkably strong, well-built man, about five feet seven inches high [five and a half inches, according to Constant], his limbs particularly well-formed, with a fine ankle and a very small foot. . . . His hands also were very small, and had the plumpness of a woman's, rather than the robustness of a man's. His eyes were light grey, his teeth good, and when he smiled the expression of his countenance was highly pleasing; when under the influence of disappointment, however, it assumed a dark, gloomy cast. His hair was of a dark brown, nearly approaching black, and there was not a grey hair among it. From his having become corpulent, he had lost much of his personal activity, and if we are to credit those who attended him, a very considerable portion of his mental energy was also gone."

On shipboard his health was, to observation, excellent, despite a heavy consumption of meat. At St. Helena, compared with other men, he was still the embodiment of vigor, and, to quote Lord Rosebery: "One is irresistibly reminded of a caged animal, walking restlessly up and down his confined den and watching the outside world with the fierce despair of his wild eye." During the first four years of his confinement he "practically passed all his days in his hut, reading, writing, talking . . . withal bored to death." The chief event for him was the arrival of books; he would "shut himself up with them for days together —bathing in them, revelling in them, feasting on them." Often he read for ten or twelve hours at a stretch. When he was not reading, his restless energy found vent in dictating his memoirs, and he dictated with a vengeance." On one occasion he kept the pens of his secretaries flying for fourteen hours, only pausing long enough to read what had been written. He sometimes dictated all night.

He would not stir abroad because he hated to be reminded of his imprisonment, his health suffered from lack of exercise and he was troubled much with scurvy, indigestion and headaches. He constructed a sort of exerciser of two beams of wood which worked like a see-saw, but this did not make up for lack of out-of-door life.

In his conversations with his physicians he showed his characteristic acute insight into the medical practice of the day. The use of physic he believed largely irrational, and he considered indiscriminate bleeding, the chief remedy of the time, the waste of so much life fluid. He praised the work of the surgeons as being founded on definite principles. He said he had himself as emperor studied anatomy for a time, but the sight of the specimens (Meneval says they were wax models) was too much for his delicate sensibilities and he gave it up. Though he always had a physician in his employ, he usually relied on the efficiency of his own simple remedies—fasting, drinking abundant water, exercise and hot baths.

"With his restless energy thrown back on himself, he was devoured by his introverted activities. He took the morbid satisfaction of a martyr in the ailments brought on partly by his confinement, and more by his rebellion against it, but finally in his last year, relinquishing the

dreams of a return to former glory, he ceased his self-commiseration and determined to live again. He rode horseback, but his main interest was in his garden." Conspicuous in red slippers and vast straw hat, and surrounded by his valets, stablemen and a gang of Chinese laborers, "he would plan and swelter and dig; for to dig he was not ashamed." He gardened as he had done everything else, on a Napoleonic scale and with Napoleonic impetuosity. The fearful Governor Lowe wrote on December 1, 1819, "Nothing can exceed the bustle and the activity which has been recently displayed by General Bonaparte, in giving directions about his flower garden, and superintending the workmen employed at it. He is hemming it in all around with as bushy trees and shrubs as he can get transplanted, and with sod walls so as to screen himself so far as possible from external observation." Individual as well as general history repeats itself, and Napoleon was shielding himself from the public gaze as he had done from his fellow students in his youthful years at Brienne.

His health had been declining gradually, but it was not until late in 1820, at the age of fifty-one, that the symptoms of his fatal malady became prominent, and it was only in April, 1821, that the seriousness of the ailment was realized by his physicians. He died on May 5 of cancer of the stomach, having retained extraordinary vigor to the last. At the postmortem examination all the organs, except the stomach, appeared sound, and his body, "far from shcwing the emaciation that usually results from prolonged inability to take food, was remarkably stout."

The physical Napoleon is not a striking figure in size, symmetry or in display of muscular prowess. What impresses us is his astonishing vigor and endurance. It was through these that he was Napoleon. Such a possession comes through heredity and not by training. Given such an inheritance, however, it requires some care to bring it to maturity, and it is significant that in his earlier years he set for himself a high standard of temperate living.

It is to be noted that Napoleon's phenomenal powers of endurance were not developed on the athletic field. Though he had the routine work of the military school he slighted some of his opportunities for physical activity, and, though football and tennis were favorite sports, we are not told that he figured in either. Such an insignificant-looking youngster would be an unlikely candidate for any "team" in our modern colleges. His play was chiefly mental, and his apparatus, books; but he stored enormous reserve of nervous energy. In this respect he resembles such other mental athletes as Michelangelo and Titian, Johnson and Scott, Beethoven and Brahms.

His capacious nervous system was backed by a vegetative machinery which was perfect. He took fastidious care of his body in many ways, and doubtless had he realized the possible effects of his obesity he would have attempted to correct that condition. He was not accused of intemperance in eating even by his enemies, and until he became emperor he certainly did not eat for pleasure but that he might get the eating done and be at work. He hated the abuse of alcohol and never in his darkest moments resorted to the use of narcotics. He considered smoking a waste of time.

Even as emperor, while he allowed his ailments and growing sensitiveness to discomfort to have some ascendancy over his former simplicity of living, he was, as compared with other men, in comparative vigor and health to the last.

The bodily unfolding of Napoleon kept pace with the successful working out of his ambitions and declined apace when the two could no longer keep company. Nothing is so conducive to health as ab-

sorbing and satisfying work, and no man ever had vaster dreams or realized them more fully up to the time of the empire. Thereafter he dreamed, but his visions were more than even he could work out, and he became confused in the maze he had created for himself. He was thrown back upon himself with disastrous friction in his nervous machinery.

The effect of all this culminated at Waterloo. The corpulent figure with head sunk between his shoulders, prevented from falling from his horse by trusty hands on either side, was but partially that of a man in diminished health or extreme fatigue. It was more that of a man for whose still phenomenal energies there was, so far as he could see, no outlet. Emotions will depress more than work, and the sight of his shattered army was too much for the man who, ten years earlier, knew no such thing as exhaustion of bodily or mental resources.

There were moral factors also that must have affected his physical nature. He is said to have come to hate war, and we know that he mourned over the loss of some of his generals. The divorce of Josephine was a severe wrench. He must have felt the emptiness of his "success," and not even his fancy could smother the fact of the instability of the position he had reached. It is little wonder that he became more and more irritable and was to his marshals a "very devil of a man."

There has been much discussion and disagreement among the critics of the battle of Waterloo as to whether the result was influenced by Napoleon's bodily ailments. A battle is a complicated piece of business, and Waterloo was no exception.

"In your profession, if you were once to fall ill, you would be a ruined man." Thus did the father of Michelangelo warn his son; but if illness could so affect the fortunes of an artist, how much more serious the slightest fall below par must have influenced the career of Napoleon on that fatal field.

More has been written about Napoleon than about any other man of modern times, and for the reason that he always remains a mystery. His physical career, being bound up with the rest, partakes of that mystery. Was the clockwork of his bodily machinery set by heredity for an early decline of his unheard-of perfection? Did that powerful machine burn itself out from very intensity of activity? Was there a decline due to a forgetfulness of the asceticism of his earlier days and negligence of certain physiological laws, and can soft living, corpulence and some trifling derangements be blamed for the falling of his star? Did pangs of conscience cause a disastrous grinding of his nervous machinery upon itself, or was it simply that the balance of political conditions in France and in Europe had finally fallen beyond his control? Probably all these factors combined to shorten the meteoric career of this man of whom Lord Rosebery wrote: "Till he had lived no one could realize that there could be . . . such prodigious vitality of mind and body."

THE WORLD AND THE BUTTERFLY

By AUSTIN H. CLARK

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TRUE appreciation of any form of animal life is quite impossible unless we constantly bear in mind the intricate and varied contacts of that form of life with other forms of life, both animal and vegetable, and also with the inanimate or inorganic world.

In order to understand and to appreciate the intricate nature of the complex, both living and non-living, that enmeshes every type of animal life, holding it rigidly to its proper and appointed place in the cosmic plan, we may consider the numerous and varied contacts of a butterfly.

Did you ever realize that for their existence butterflies depend upon the sea? The young of butterflies are known to us as caterpillars. Caterpillars eat leaves—or at least the great majority eat leaves. Leaves are produced by plants. In order to grow, plants must have water. Water comes to them in the form of rain. Rain is moisture condensed from the air passing in the form of winds above the earth. Most of this moisture gets into the air through evaporation from the surface of the seas which cover seven tenths of the area of the world.

So there really is a close connection between the butterflies and the ocean. This connection is made up of many links which involve almost every line of science.

For instance, astronomy plays a part. The emanations from the sun provide the energy by means of which the water is evaporated from the surface of the sea, which causes the winds to blow, and which, acting on the green substance in the leaves of plants, enables them to form organic out of inorganic substances.

In other words, the emanations from the sun make possible the physical processes and chemical reactions on which the existence of the butterflies depends. And besides this, the element of time, so far as it affects life, is an astronomical phenomenon dependent upon the spinning of the earth upon its axis and on its course about the sun.

Weather and climate play an important part in directly affecting the lives of all the butterflies. They also affect them indirectly through their action on the sea, in some cases thousands of miles away. As an example, the alpine butterflies on the mountain tops in south central Asia depend on snow and rain which is brought to that region in the form of water vapor by the higher currents of the air from the Atlantic Ocean across the plains of Europe and of western Asia.

Soils are formed from the disintegration of the rocks. Rocks are continually breaking up and being washed away as mud or sand or gravel. In this way is formed the basic food of the plants which support the butterflies.

Besides this, the muds and sands and gravels deposited in water are continually being reformed and consolidated into the so-called sedimentary rocks. Once in a while a butterfly gets stuck in mud and covered up. This mud may later turn to rock. When this happens we have a record of the sort of butterflies that existed at the time when that rock was mud. It is quite unusual to find butterflies as fossils in the rocks, though a fair number have been found and studied.

These fossil butterflies all belong to that far-distant period known as the Miocene and lived many millions of

years ago. In spite of their very great antiquity they differ very little from the kinds we know to-day. Most of their living representatives, however, are found in different regions. Thus in Colorado we find a type now confined to Africa, and in Germany we find other types which to-day live only in America.

Most caterpillars are able to subsist only on a very limited number of different kinds of plants which are closely related to each other in their chemical composition. The cabbage butterfly feeds only on cabbages and a few closely related plants and on nasturtiums.

Some enormous groups of butterflies feed only on a single type of plant, as the so-called *Aristolochia* swallowtails which feed only on *Aristolochias*, and also our fritillaries, which feed almost exclusively on violets. Very many kinds of butterflies feed only on a single kind of plant, like our beaked butterfly and tawny emperor which as caterpillars are found only on hackberry trees. But a few kinds of butterflies, like our common yellow swallowtail, feed on a very great variety of different and unrelated plants.

From this it becomes evident that female butterflies must be expert botanists, for they must be able accurately to identify those plants which are suitable for use as food by the caterpillars of the coming generation. Or perhaps it should be said that they must be expert chemists, for they not infrequently will pick out a plant chemically suitable as food, but botanically widely different from any other plant which they or their ancestors—at least for thousands of generations—could be supposed to know.

As an illustration, the female of the common cabbage butterfly will freely lay her eggs on garden nasturtiums (*Tropaeolum*) which belong to a family of plants (Tropaeolaceae) confined to Central and South America and not at all like any of the plants of the cabbage family (Brassicaceæ) upon which ordinarily this Old World insect feeds.

Butterflies have very many enemies of every conceivable description. The Australian natives are very fond of certain kinds of butterflies, and grow fat on them if they can get them in sufficient quantities. In Central and South America and especially in Africa the caterpillars of several kinds of butterflies used to be—and in some places still are—in much demand for food.

Certain bats are very fond of butterflies, and mice and shrews eagerly devour them. Some birds feed partly, and in the tropics largely, on them. Certain small lizards and some of the smaller snakes are very fond of them. Among their insect enemies are mantises, various predacious bugs, robberflies, dragonflies, hornets, ants and the so-called caterpillar wasps.

But their worst and most destructive enemies are various sorts of small wasp-like flies which lay their eggs upon or in their eggs, their caterpillars or their chrysalids. The small maggots which hatch from the minute eggs of these parasites feed upon the contents of the egg of the butterfly or upon the juices of the caterpillar or upon the contents of the chrysalids. Some of the true flies which in their appearance are much like little blue-bottles also have this parasitic habit. And besides these enemies butterflies have many more, for instance, nematode worms, gordian worms, bacteria and protozoans, spiders and mites and sometimes even mosquitoes.

Such in brief are the more important contacts of a butterfly. In considering the living world it is important constantly to bear in mind that every sort of animal, no matter what it is, has just as many and just as varied contacts as has a butterfly.

SPECIALIZED EDUCATION AND ITS VICES

By Dr. D. B. KEYES

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WE have been told by writers all over the world that this is the age of specialization. Success comes to those who know considerable about one small, narrow field and little or nothing about many fields. This doctrine has been preached in the universities of the country. Even our science students have been led to believe that success in applied science depends on rigid specialization. Young men who intend to go into research and development work in industries, especially work involving physics and chemistry, have often been told that they must become experts in some narrow field of physics or chemistry before they can possibly hope for success.

The actual experience of our graduate students in industry has been quite to the contrary. The specialist in research and development in the industry has rarely been successful, whereas the boy who had a good fundamental knowledge of science and who was not anxious to specialize in any particular branch was easily adaptable to any research investigation and was frequently highly successful in his work.

The difficulty seems to lie in a lack of appreciation of the time necessary to make a specialist. The prominent specialists to-day have spent their entire lives acquiring the necessary knowledge to attain the position they now occupy. Four to seven years in a university will never produce a specialist of any importance.

The industries appreciate this condition, and there is a marked tendency in the last two or three years on the part of research directors and employment managers to ask for students who have had a thorough fundamental education in the three common sciences—mathematics, physics and chemistry. To-day they are specifically requesting that no specialized work of any kind be required in the curriculum. There is a marked tendency on the part of these industrial men to select for research and development boys who have been trained in the chemistry or chemical engineering curricula simply because these boys are better educated in the fundamental sciences. The engineering student is being used as an operator in the plant or as a mechanic in the development division. The young physicist is used sparingly in the research laboratory and could be used to a far greater extent if he would be willing to acquire a fundamental knowledge of chemistry.

This refusal on the part of the engineering student and the physicist to accept chemistry as an important study is very interesting from a psychological standpoint. On the other hand, the student of chemistry is very anxious to acquire all the physics that he possibly can. He is even willing to take as an elective course something which involves the application of physics, for example, courses in mechanical engineering and electrical engineering. He does not, however, consider these courses of great fundamental importance even though they may be extremely interesting.

It is also interesting to note why it is that specialization in education as regards applied science is often fatal in research work. The reason is extremely simple. The research problems of industries refuse to stay within the narrow limits of a definite applied science field. Steel manufacturing, for example, may involve problems in bacteriology. One would hardly criticize the young man who was going into steel manufac-

ture if he failed to take a course in bacteriology.

Another factor involved in specialized education is the question of placement of the graduate. It is the common occurrence that a young man who is trained for one particular industry has a very good chance to go into some other industry. Over half of the graduates of one of our most specialized engineering institutions go into a different line from the one for which they were trained.

Some years ago the electrical engineering department in one of our universities took over the problem of investigating the cause and prevention of failure of electric cables. The investigators were electrical engineers and they found, first of all, that it was necessary to devise a machine that would detect insulation flaws in a cable before it was put in service. This proved to be a rather difficult problem. A physicist well trained in electrical physics was called on to aid the investigators. Finally the problem of producing a testing machine for this purpose was solved. Then it became necessary to investigate the cause of insulation failure after the cable had been in use for a period of time. It was hoped that a method of testing could be devised that would predetermine the failure of insulation after a period of use. Chemists were added to the investigational staff, and this work is now in progress. It may be necessary to add botanists and other scientists before the problem is finally solved.

For many years ice manufacture in this country has been in the hands of refrigerating engineers as far as its technical development is concerned. These gentlemen are the type of men who have confined themselves largely to this one industry. Naturally their knowledge of physics and chemistry on the whole is limited. Development of the refrigeration industry has been along mechanical lines. At the present time in this country there are probably ten thousand ice plants that are operating at a very low efficiency because of water difficulties. The amount of the salt and the character of the salt present in the water determine whether or not a clear salable cake of ice can be made by ordinary methods. Distilled water is expensive, but is often necessary in localities where the raw water is not fit for ice manufacture.

Recently a research investigation headed by a physical chemist has been undertaken to study the water treatment for ice manufacture. In less than a year, treating the subject from a fundamental scientific standpoint, it was discovered that all waters can be so acted upon that they will make satisfactory, clear, transparent ice without resorting to distillation. A study of crystal growth showed the cause of opaque ice and also indicated several methods of prevention. A study of salt solubility resulted in a new method of removing sodium salts from water even when present in relatively small quantities without resorting to expensive reagents. It is interesting to remember that this investigation brought results within a year which will completely revolutionize a large proportion of the ice plants in this country, and that this research work was done by a young man who had a fundamental training in science but who had never seen the inside of an ice plant and who was not even familiar with any phase of refrigerating engineering.

For many years steam boilers in this country have blown up for one cause or another. Some years ago a peculiar kind of cracking was noticed in boiler shells which often proved disastrous. This type of cracking, now known as embrittlement, has been found in a great many boilers throughout this country and abroad. Mechanical engineers and metallurgists have made serious attempts to solve this problem without any apparent success. A few years ago

an investigation was started headed by an industrial chemist, a young man who had a thorough training in science and some research experience in various industries. To-day the cause is known to be concentration of caustic in the boiler water within a seam coupled with physical stress. The prevention is quite obvious. It is necessary to precipitate within this seam some solid material which is inactive towards the steel but will prevent accumulation and concentration of sodium hydroxide in the same space. A fundamental study based on the solubilities is all that is necessary to give a thorough understanding of the problem and indicate a satisfactory remedy.

There are many other cases which indicate quite clearly the importance of a fundamental training in research involving great industrial problems. An excellent recent example is the determination of the cause of corrosion by flue gases in our great power-houses. It has always been thought that sulphur oxides or sulphuric acid was the primary cause of corrosion of economizer tubes, etc. A fundamental study by a young man thoroughly trained in chemistry, physics and mathematics has indicated that sulphuric acid alone is of very little importance; that a solid material, ferric sulphate, is largely responsible for the corrosion of the steel tubes.

It is interesting to note that the type of problems mentioned above when once successfully solved represent an actual financial return of over a million dollars per year. This sum does not represent the entire benefit derived from such research but represents only the benefit derived by a single company from a single research project. Furthermore, the amount represents the tangible value of the benefit and does not involve such items as good-will.

There seems to be no question but that the research worker, young and inexperienced though he may be, who is well trained in fundamental science is quite able to do research work which has immediate application and is of great financial value.

If one is willing to recognize the above statement, it then becomes an interesting topic of discussion as to why our educational institutions should continue to train a great many bright, energetic young men in applied subjects which they have little or no chance of ever using and at the same time fail to train them in the fundamental sciences. Previously it has always been maintained that the young man who has been trained only in the fundamental sciences is unable to do work of practical importance. Experience in the last few years, especially in the chemical and allied industries, has proved this statement to be absolutely incorrect. These industries have found that only the young man who is giving his entire time and attention to fundamental subjects has been equal to the task set before him in the research and investigational department of our great industries. Many of the industrial executives appreciate this fact, as is illustrated by the tremendous demand for a young man trained in the fundamentals. The universities, on the other hand, have been slow in coming to this conclusion, and we still find enormous sums of money spent for the education of youths along the so-called practical lines. These boys end up as operators and usually finally leave their profession for a business career in order to make more money and at the same time have an opportunity to utilize their natural ingenuity.

This is not exactly a pleasant fact to face. Furthermore, we can not hope that our great universities will change over abruptly in the near future to a more sane view-point of education. As in all large institutions, developments within their organization are slow. It will take many years before the principal educational institutions in this country will realize that a broad training in the fundamental sciences is far superior to premature specialization for the boy who wishes to do industrial research.

SOMETHING ABOUT VITALISM AND MECHANISM

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THERE is life in a chunk of copper. Must we revere it, add its perplexities to those things which transcend our understanding? Should we accept it on a par with animal and plant life, describe and index it? Or can we ignore it, turn it over to the vitalist, the mechanist, and quietly watch the ensuing controversy? Rather than be served with predigested mental food let us examine the dogmas of the past, the tenets of the present.

Disregarding earlier culture than that of the Greeks, we are led to believe that many perplexing phenomena were given anthropomorphic or mythological explanations. From these explanations a crude form of science emanated. Then followed a more critical observation and study of the phenomena of the heavenly bodies, the first evidence we have of scientific ideas, which laid the foundation for astronomy, a science. Nevertheless, it was not until Aristotle (384–322 B. C.) advanced the first pure line of reasoning that mythology began to give way to science. Beginning at this point, I shall try to catalogue some of the more important scientific advances made by man in approaching our modern concepts, since it is altogether through the development of science that the vitalist and the mechanist became convincingly contradictory.

Aristotle, cited by the vitalist, upheld the following concrete views: That the universe is made up of nature, God and man; that nature, definite combinations of the four elements classified by Empedocles (450 B. C.) as earth, water, air and fire, plus Aristotle's thoughtful addition of ether and stars, made up animals, plants, water, earth, the moon and stars; that God is the cause of known effects, and man is a combination of the natural and divine; that plants are organisms with a nutritive soul; animals, organisms which have a nutritive, sensitive, oretic and locomotive soul; and man, an organism which has the aforementioned characteristics plus a rational soul, styled the intellect; and finally that it is the intellect through which man approaches God. What a paradoxical nicety!

Though the advances made by Aristotle and the many subsequent steps hesitatingly taken by science have been summarily retracted, it is interesting to note that the contributions made by Euclid (third century B. C.), who is regarded as either the discoverer or compiler of Euclidean geometry, continued in use for twenty centuries. It is a startling fact that now, however, we are forced to admit that Euclidean geometry is used as a matter of academic convenience only, since we must rely on another system of geometry to include the phenomena of the universe. We must now take cognizance of the geometrical difficulties peculiar to each of the other planets.

Equally interesting is the origin of mechanics and hydrostatics which is identified with Archimedes (287–212 B. C.), who presented two axioms: First, that equal weights placed at equal distances from the point of support of a bar will balance; and second, that equal weights placed at unequal distances do not balance, but that which

hangs at the greater distance descends. How easy and diabolical it would be at the present time to confuse Archimedes by introducing magnetic or electric influences, which were unknown to him!

Though Lucretius (98–55 B. C.) was essentially a poet, it is quite possible that he reflects the ideas of his contemporaries in stating that all forms of life merely appeared, while only those fittest to survive persisted and reared offspring. He furthermore denies the doctrines of supernatural government of the world and a future life. These ideas, ignored through centuries, appear to be somewhat similar to those held by some of the present-day emergent evolutionists.

The Dark Ages, or perhaps more accurately the period of ecclesiastic enlightenment, took firm hold on thought and put an abrupt stop to any undesirable controversy between vitalists and embryo-mechanists. Likewise the use of experimental methods for exploring the secrets of the natural phenomena was completely discouraged because experimentation was considered a danger to theological orthodoxy. A review of this attitude of intolerance, which so thoroughly stagnated scientific research, undoubtedly antagonizes many modern scientists to such a degree that they unhesitatingly discard the vitalistic view-point, feeling that vitalism is too closely bound to theology and metaphysics. There is a feeling of tolerant fondness, however, for the alchemists, who, even though their experimental efforts were tinged with mystical analogies, nevertheless carried on experimental work for over three hundred perilous years, perilous merely because their work was not accepted by orthodox theology.

A forward step was taken in the thirteenth century when Aristotle's philosophy, being duly reconciled and adopted by Christian theology, was reimported into the schools of Europe. Roger Bacon (1214–94) showed a keen intellect in working away from theology and metaphysics and in pursuing a study of physical science by experiment in the Aristotelian way. He fought the cultivation of science based on arguments deduced from premises resting on authority or custom, gave himself up to experimental research and lived to be eighty years old!

The fifteenth and sixteenth centuries, the Renaissance, ushered in many startling scientific discoveries. Chief among the factors which made such discoveries possible were the temporary diminution in power of the papacy, printing, the recovery of the Greek language and the consequent spread of the naturalistic view of the universe which had been current among the Greeks, instead of the mystical view expounded by the medieval schoolmen and ecclesiastics. Scientific research consequently prospered under the leadership of such men as Leonardo da Vinci (1452–1519), who, besides exhibiting many other accomplishments, followed mathematical and physical research, grasping hold of the laws and applications of mechanical forces; Copernicus (1473–1543), who developed the heliocentric theory; Francis Bacon (1561–1626), who set out to gain knowledge through experimental research as a corrective to medieval philosophy; Galileo (1564–1642), who paved the way for Newton by opening the science of dynamics, and William Harvey (1578–1657), who discovered the significance of blood and its circulation.

Newton (1642–1727), by discovering the laws of gravitation, brought the solar system into the cognizance of known dynamical principles. James Hutton (1726–97) and Charles Lyell (1798–1875), the founders of geology, expanded knowledge in time as enormously as Newton had expanded knowledge in

space. Laplace (1749–1827), joining in the tireless effort of scientists to eliminate the mystical, advanced the idea of a primitive state of nebulosity from which, by the action of known dynamical processes, the sun and planets would be evolved. Lagrange (1736–1813), a mathematician, fitted the theory of mechanics to certain formulas. By the development of the calculus of variations he largely verified the Newtonian theory.

Galvani (1737–98), physiologist, correlated the relations of animal functions to electricity, while Volta (1745–1827), a physicist, conducted experiments on contact electricity, and thus many more mysterious body functions were made comprehensible. Another step towards mental clarification was taken by Lavoisier (1743–94), a chemist, who overthrew Stahl's (1660–1734) phlogistic doctrine and broke the theory that redistilled water would yield earth. One by one the inexplicable mysteries of life which so grandly transcended human understanding were stripped of mysticism and subsequently clothed in substantial scientific theories.

Lamarck (1744–1829) explained new species on the theory of the effect of use and inheritance of acquired characteristics. Darwin (1809–82) offered survival of the fittest and occurrences of "sports." Evolution, then, became something which can make the theories of origin intelligible. Many other mysteries were removed by Mendel (1822–84), whose work on inheritance was rediscovered in 1901. The sacredness of heredity yielded to a mechanistic explanation—the theory of the gene, together with the concepts of the influences of environment, presented formidable weapons for the mechanist. The vitalist, though, can still challenge the inherited intellect to explain itself—demand an explanation, mechanically, for the intellect which Aristotle held to be "that through which man approaches God."

Our understanding of the nature of a bar of copper was made much clearer by Dalton (1766–1844), who developed the atomic theory. Ampère (1775–1836) established the field of electrodynamics from his work on electricity and magnetism. Wohler (1800–82) dealt "vital forces" a blow by artificially preparing urea, thereby breaking down the barrier held to exist between organic and inorganic chemistry, between life and nonlife. Thereupon the chasm between a bar of copper and animal life was greatly lessened and the idea of spanning the rift was no longer held to be an enormity.

Faraday (1791–1867) cleared up induction of electric currents and electromagnetism. It is interesting to note that Faraday, eminently successful in experimental research, held a distinct belief in God from whom he believed emanated a power above us. He consequently found nothing incompatible in the idea of things that can be known by man-spirit and higher things that can not be known by that spirit.

Stokes (1819–1903), Bunsen (1811–98) and Kirchhoff (1824–87) discovered that the spectroscope gave a means of investigating the chemical composition of the sun and stars, and so brought another set of phenomena under the control of terrestrial experiment, thereby removing the marvels of the firmament which had completely transcended our understanding.

Schleiden (1804–81), before engaging in the obscurities of philosophical and historical studies, discovered cells and the nucleus and determined that a nucleated cell is the only original constituent of the plant embryo. Schwann (1810–82) established unexpected accord in the plant and animal cell and nucleus, hence the cell theory and foundation of modern histology. Virchow

(1821–1902), from studies of cellular pathology and classification of tissues, developed the science of pathology. He also placed the science of anthropology on a sound critical basis. These discoveries naturally allowed animal and plant life to be unified and even supported the view that man was an animal—all this without the hue and cry of heresy.

Pasteur (1822–95) ended the dispute on wholesale spontaneous generation. He not only revolutionized surgery but instigated studies in preventive and curative medicine. Not so well known and of less pertinent value to us legally is the fact that he created a new era in the brewing and wine-making industries. Weismann (1834–1914) developed the germ-plasm theory of heredity and with that indicated an earthly immortality of protoplasm—if we must have immortality.

Gibbs (1839–1903), the founder of chemical energetics, was the first to apply the second law of thermodynamics to the exhaustive discussion of the relation between chemical, electrical and thermal energy and the capacity for external work. J. J. Thomson (1856–——), by continuing Faraday's work, developed the electron, and Lorentz (1853——) formed the theory of electrons within the atom. He suggested occasional instability of the atom—radioactivity—hence the chemical atom, hitherto believed indestructible and eternal, has succumbed to evolution.

Maxwell (1831–79), by studies of the properties and velocity of propagation of light and electromagnetic waves, decided they were identical, thereby making light an electromagnetic phenomenon. Planck (1868–) studied radiation and advanced the quantum theory, namely, that emission of heat radiation proceeds discontinuously, in quanta, while absorption is continuous. Lately, however, the applications of the revolutionary quantum theory are being critically questioned.

Loeb (1859–1924) aimed at the real distinction between living and dead matter. His working hypothesis was that all living things are chemical machines and their workings are open to the same mechanistic explanation as are those machines made of inert matter. His experimental researches with tropisms and artificial parthenogenesis yielded much material for the mechanist.

Sir Oliver Lodge (1851–) undertook to reconcile science and religion. His energies, first devoted to pioneer work in the field of wireless telegraphy, later became involved in psychical research, in which field he endeavored to discover a means of communication with the dead. A quotation, however, will acquaint us with Lodge's critical attitude.

> Speaking of cohesion, Sir Oliver Lodge once remarked that it was as yet an inexplicable fact that when one end of a rod is pushed the other end moves, to which *Punch* retorted that it was an equally inexplicable fact that when one end of a man is trodden upon the other end shouts.[1]

There, for the majority, ended a serious contemplation of Lodge's challenge.

Many other workers contributed information which led away from the mysterious unknown. Energy was studied and became as evident as mass, and both mass and energy in the universe were held to be constant, until the introduction of Einstein's theory of relativity. Einstein is now said to have succeeded in devising mathematical formulas which bring under a single set of laws the phenomena of electricity and magnetism with those of gravitation. Undoubtedly science has progressed rapidly since the adoption of research methods demanding observation, hypothesis, deduction and experimental verification.

[1] Swann, *Science*, November 2, 1928.

With each scientific discovery the mechanist naturally feels that the ultimate explanation of the hitherto mysterious phenomenon is fundamentally a mechanical one. The ease with which a phenomenon can be explained and understood when terms of mechanical conceptions are employed tends to convince the mechanist that he is presenting the most logical explanation available: this in noble contrast to the vitalist who must abide by a belief in the inexplicable, life. Ever since the adaptation of mechanical means of supplanting our muscular energy, we have been inclined to view force as a mechanical conception. Though magnetism or electricity, completely unknown and miraculously avoided, did not confuse Archimedes in crystallizing the idea of mechanics and hydrostatics, his followers were mystified and misunderstood until they explained these phenomena in terms of mechanics. Consequently the immediate difficulty facing the mechanist is that, though a greater signification may be reached by reducing all possible phenomena to mechanical conceptions than by employing mechanics in terms of electricity, magnetism or gravitation, mechanics is not philosophically the most fundamental science.

The main question of vitalism, according to Driesch,[2] is whether the purposiveness in those processes is the result of a special constellation of factors known already to the sciences of the inorganic, or whether it is the result of an autonomy peculiar to the processes themselves. He used the term *static teleology* to imply the meaning held by the mechanistic theory of the organism, and *dynamic teleology* to signify the vitalistic theory, "autonomy of vital processes."

The vitalists are subjected to such conditions as these: that all believers in epigenesis are vitalists; that many "unwelcome adherents" claim to be vitalists; that the theory of vitalism has died or has not died, according to the conviction of the vitalist, to be recrystallized in neovitalism. In other words, the vitalistic theory has changed in concept as much as science has; in fact, so great are such changes that a person's scientific or vitalistic ideas of a decade ago are not subscribed to to-day. That the mechanists are faced with similar difficulties is to be expected.

In discussing the play "RUR" with a friend, I pointed out that in the play mankind had created mechanical men, robots, which carried on all necessary and irksome tasks until they revolted and killed all mankind. It was then merely a matter of time until the robots themselves would rust and wear out. We granted the possibility of making such robots, even that robots could be made which could make "baby robots," but balked at the idea of making robots which could design or create other distinct types of robots. Mechanics then, though carried to an astounding degree, would nevertheless lack a vital something.

W. F. G. Swann, a physicist, gives a most timely warning to those who seek to become extreme mechanists. He divided the activities of living things into three classes as regards their relation to physics. First, the class which is understandable in terms of physics or chemistry, such as cell osmosis; second, the class which has not been duplicated in the laboratory in such a manner as to provide a quantitatively satisfactory explanation of the actions of the organism, as many chemical reactions which take place in the non-living protoplasm but occur with increased velocity in the otherwise indistinguishable living protoplasm, and third, that class, if there be such a class, which comprises those phenomena of life which require a definite

[2] "The History and Theory of Vitalism," 1914.

appeal to a wider system of laws than those comprised under chemical or physical laws in the ordinary sense of the word. Quoting Swann:

> The fact that vital phenomena do not make themselves immediately evident in so-called non-living matter is no criterion as to the certainty of their complete absence. It is, in fact, not inconceivable that the existence of completely non-living matter as such would be unstable, and that the living activity might increase, perhaps slowly at first, but possibly at an increasing rate, until, at any rate in the presence of suitable conditions and environment, it finally attained a steady state in which there was a definite equilibrium between the living and the non-living matter.

Jackson, a mathematician, writes:

> Having been impressed at an uncritical age with the principle of the conservation of energy, I awoke to a painful realization that I did not know what energy meant, and the more I tried to find out, the more I was puzzled by the alleged importance of the conservation of so remote an abstraction, until it dawned on me in a flash of illumination that the importance of energy lay in the fact that it was the thing that was conserved. The discovery of the existence of such a unifying permanence by the creators of the science was one of the things that made mathematical physics possible. It is not apparent that there exists any small group of variables sufficient to characterize the phenomena of a living organism. A physical body is more or less homogeneous, or can be so considered for the purposes of argument. With an organism this is not the case. Statistical prediction deals with organisms in the mass, while our vital human concerns are with organisms as individuals; and the individual has a complexity of parts, which demand separate consideration with regard to their several functions. There is no prospect, humanly speaking, that we shall ever have methods for the practical handling of complicated differential equations in several dozen or several million variables. In the controversy between mechanist and vitalist, between behaviorist and subjectivist, the part of the mathematician must occasionally be the inglorious one of counseling moderation. He is too familiar with the limitations of calculations to see in them, or in the present limitations of any science, need for invoking supernatural intervention. But when he considers that an exhaustive discussion of the dynamics of a single atom of helium transcends our powers for the time being, and lifts his eyes from an atom of helium successively to an atom of carbon, a molecule of sugar, a molecule of protoplasmic substance, a living cell, a toadstool, a tree, a guinea-pig and a professor of mathematics, he does not look for any early reduction of the laws of life to a system of differential equations which he can integrate.

It appears, then, that mechanism can not withstand critical analysis. Why should it, when the working principles of scientists can not be said to be founded on a single infallible assumption? On the other hand, the vitalist who revels in the fallibility of the human mind is nothing but a mystic: he shirks mental activity and succumbs to mental indolence, or else he embarks on circuitous mental adventures. The vitalist, though, who adopts the doctrine "that life is the basic reality, of which everything else is a form or manifestation" must be considered with respect, especially if he is able to differentiate life from non-life.

Confused as we are by the ineptitudes of vitalism and mechanism, intimidated by the crashing of one doctrine after another, crushed by the restriction of mental facility, still we dare to affirm and deny. We may grandly admit that there is life in a chunk of copper, thereby avoiding the possibility of being dubbed "dogmatic." We can not believe, however, that the life in the copper would worry about appearing to be dogmatic.

MATHEMATICS IN THE SOCIAL SCIENCES[1]

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THE invitation to deliver this lecture was accepted chiefly because of my veneration for J. Willard Gibbs, whose pupil I was forty years ago.

It was by accident rather than by design that my own life work was diverted from mathematical physics and mathematics, which it was my privilege to study under Gibbs, and was turned, instead, toward the application of mathematics to the social sciences. While I have lost touch with the subject of which J. Willard Gibbs was a master, the debt which I owe to him and the help which my studies with him have afforded me even in the field of the social sciences can never be forgotten.

I hope, therefore, it may not be amiss to precede what I have to say on mathematics in the social sciences by a reminiscent statement of my personal impressions of Gibbs himself. J. Willard Gibbs towered head and shoulders above any other intellect with which I have come in contact. I had a keen realization of his greatness even in those formative years in Yale College and the Yale Graduate School. But this keen realization has grown even keener as the years have swept by, not only because of the increased evidence of the fundamental value of Gibbs's work in his own chosen field but also because in my own consciousness, after so many details have dropped from memory, there persists all the more clearly the strong impression which Gibbs's personality and teaching made upon me.

In saying this I do not think I can be accused of undue enthusiasm simply from the loyalty of a pupil to his teacher, especially in view of the statements of Lord Kelvin and others which virtually rank Gibbs as the Sir Isaac Newton of America. Lord Kelvin said, when visiting at Yale a few years ago, that "by the year 2000 Yale would be best known to the world for having produced J. Willard Gibbs."

One of the most striking characterizations of Gibbs was recently made by Dr. John Johnston, now with the United States Steel Corporation, then professor of chemistry at Yale, in his address on Gibbs delivered at Yale University two years ago. He stated that no result of Gibbs's work had yet been overthrown, and that, in this respect, Gibbs seems to stand unique and supreme among the great scientists.

The English physical chemist, Professor F. G. Donnan, has said that "Gibbs ranks with men like Newton, Lagrange and Hamilton, who by the sheer force and power of their minds have produced those generalized statements of scientific law which mark epochs in the advance of exact knowledge. . . . The work and inspiration of Gibbs have thus produced not only a great science but also an equally great practice. There is, to-day, no great chemical or metallurgical industry that does not depend, for the development and control of a great part of its operations, on an understanding and application of dynamic chemistry and the geometrical theory of heterogeneous equilibria."

Professor Ostwald said, in the preface to his German translation of Gibbs's thermodynamic papers in 1892:

> The importance of the thermodynamic papers of Willard Gibbs can best be indicated by the fact that in them is contained, explicitly or implicitly, a large part of the discoveries which have since been made by various investigators in the domain of chemical and physical equilibrium and which have led to so notable a de-

[1] The J. Willard Gibbs lecture before the American Mathematical Society, American Association for the Advancement of Science, Des Moines, Iowa, December 31, 1929.

velopment in this field. . . . The contents of this work are to-day of immediate importance and by no means of merely historical value. For of the almost boundless wealth of results which it contains, or to which it points the way, only a small part has up to the present time [1892] been made fruitful.

Sir Joseph Lamor said:

This monumental memoir ["On the Equilibrium of Heterogeneous Substances"] made a clean sweep of the subject, and workers in the modern experimental science of physical chemistry have returned to it again and again to find their empirical principles forecasted in the light of pure theory and to derive fresh inspiration for new departures.

We think no less of Gibbs's greatness because he himself showed so little consciousness of it. He must have realized the fundamental character of his work. But his pupils remarked his profound modesty and often commented on it. His chief delight was in truth-seeking for its own sake, and he was so intent on this search that he had no time even to think of emphasizing the originality or value of his own addition to the great vista of truth over which his mind swept. Doubtless he often did not know or greatly care where the work of others ceased and his own began. He did not always wade through the literature which preceded his own scientific papers. I remember hearing him say that when he wanted to verify another man's results he usually found it easier to work them out for himself than to follow the other man's own course of reasoning. This was said without any affectation, but simply in a jocular vein, as by one who would escape a difficult task by going his own way. But even though it may be difficult to disentangle what was original in Gibbs's work from what was anticipated by others, surely no competent person doubts to-day that he founded a new era in physics and chemistry.

Because of his retiring disposition and the theoretical nature of his work, he was, during his lifetime, almost unknown except among a few special students. The majority of students at Yale in my day did not know of his existence, much less of his greatness. And there were far fewer people in America than there were in Europe who could appreciate what he was doing.

His work was more promptly recognized in Germany. When I studied in Berlin in 1893, and was asked under whom I had studied in America, I enumerated the mathematicians at Yale. To my mortification not one of the names was known to those Berlin professors, until I mentioned Gibbs, whereupon they were loud in his praises. *"Geebs, Geebs, jawohl, ausgezeichnet!"*

Even to-day, Gibbs illustrates the rule that a prophet is not without honor save in his own country. As Professor Johnston noted, the fiftieth anniversary of the publication of the first part of Gibbs's great work "On the Equilibrium of Heterogeneous Substances" was signalized in Holland by the publication of a Gibbs number of their chemical journal. This contained contributions from Dutch authorities as well as from French, German, Canadian, Norwegian and English authorities—but none from an American!

It is true, however, that at Yale we have finally established a Gibbs fund for a lectureship to be filled by visiting professors and that a new complete edition of his works has been issued by Longmans, Green and Company. It is also planned to issue two volumes of commentation on Gibbs's work to make its chief results more accessible to the general scientist. I am proud to have played a part in securing these. May I take this opportunity to say that I am also proud to have been included among the J. Willard Gibbs lecturers? And may I congratulate the American Mathematical Society on being the organization to found this lectureship, although Gibbs was professedly not so much a mathematician as a physicist. The only other Gibbs lectureship seems to be that at the Mellon Institute in Pittsburgh.

The Chicago Section of the American Chemical Society awards a J. Willard Gibbs medal annually, the recipient of which makes an address.

Presumably Gibbs's greatest contribution to science was his application of the laws of thermodynamics to chemistry. He made this almost a deductive science. Professor Bumstead said of his work:

> To an unusual extent, among the sciences which appeal to experiment, it can be, and has been, cast in a deductive form. Sir Isaac Newton said that "it is the glory of geometry that from a few principles it is able to produce so many things." Thermodynamics shares in this kind of glory; it has only two fundamental principles, of which the first is a statement of the conservation of energy as applied to heat, and the second states the fact (so deeply founded in general experience that it seems almost axiomatic) that heat will not, of itself, flow from a body at a lower temperature to one of a higher temperature. From these two simple principles, by an almost Euclidean method, a surprising number of facts and relations between work and heat, and various properties of bodies were deduced about the middle of the last century.

J. Willard Gibbs was certainly a master at producing many deductions from a few general principles. And it was just because of the generality of the principles from which he always insisted on starting that he succeeded in reaching such a wealth of conclusions.

In fact, it has always seemed to me that Gibbs's chief intellectual characteristic consisted in his tendency to make his reasoning as general as possible, to get the maximum of results from the minimum of hypotheses. I shall never forget, and have often quoted, an aphorism used by Gibbs, whether or not original with him, to the effect that "the whole is simpler than its parts." For instance, when he had a problem involving coordinates he preferred to employ an *indeterminate* origin, maintaining that his results were thereby rendered simpler and easier than if he took the origin at some apparently more convenient but special point in relation to the crystal or other conformation which he was discussing. When the origin is indeterminate it automatically effaces itself from all the general relations deduced.

Many if not most other investigators instinctively seek to solve special cases before attempting to solve the general case. Sometimes they pay a big penalty in needless experimentation. I remember Professor Bumstead, my fellow student at Yale, recounting with relish a conversation that Gibbs was reputed to have had with a youthful investigator who had made a laborious experimental study of certain relationships and who was, with pardonable pride, telling Gibbs of his conclusion. After listening attentively Professor Gibbs quite naturally and unaffectedly closed his eyes, thought a moment, and said, "Yes, that would be true," seeing at once that the special result which this young investigator had reached was a necessary corollary of Gibbs's own more general results. For him, it required no experimental verification. The young man's work had, from Gibbs's view-point, been almost as much wasted as if it had been spent in a laborious set of measurements of right angle triangles on the basis of which measurements he should announce as a new and experimental discovery that the square of the hypotenuse is equal to the sum of the squares of the other two sides. It is worth noting that, though Gibbs did his work in the Sloane Physics Laboratory, he never, as far as I know at least, performed a single experiment. His life work, stupendous as it was, and based as it was on concrete fact, consisted exclusively in new deductions from old results, the full significance of which no one else had been able to derive.

In his effort to represent physical relations by geometrical models and to portray the theory of electricity and magnetism by geometrical methods, Gibbs encountered the need of a new vector analysis to replace the awkward analysis by Cartesian coordinates, requiring, as

that does, three times as many equations to write and manipulate as does vector analysis, not to say diverting attention from the lines and surfaces actually involved to their projections on three arbitrary axes.

To me the most interesting course I had with Gibbs was on vector analysis. He believed he had simplified the Hamilton system of quaternions, getting his cue from Grassmann's "Ausdehnungslehre." But he was so conscious of his obligations to Grassmann that he was reluctant to publish his own system, apparently doubting whether it possessed enough originality to warrant publication. He therefore had privately printed a syllabus of his system and this reprint was used by us in his class as a text. Only after many years did Professor E. B. Wilson construct a more elaborate text-book embodying Gibbs's principles of vector analysis.

It is a curious fact that, while Gibbs's work in thermodynamics was appreciated in German, his work in vector analysis was not. I remember the comment of Professor Schwartz at Berlin, when I undertook to defend Gibbs's vector analysis: *"Es ist zu willkürlich."* The Germans felt in honor bound to restrict pure mathematics to mere elaboration of the proposition that one and one makes two. Starting with this proposition, by successive additions or subtractions of unity, we may, of course, by going forward, obtain all the positive integers; this is addition. Reversing, we obtain zero and the negative integers; this is subtraction. Then, by applying repeated addition or multiplication and repeated subtraction or division, repeated multiplication or involution and repeated division or evolution, we arrive at fractions, surds, imaginary quantities and finally the "complex variable" $x+y\sqrt{-1}$. But beyond this, by such processes no more general form of magnitude can possibly be derived; for, if we operate on a complex variable by addition, subtraction, multiplication, division, involution or evolution, under the recognized rules of algebra, we obtain simply other complex variables and nothing else whatsoever. Only by changing, or as the German critics would say, by violating, the fundamental rules of algebra faithfully followed in the above processes, such as the rule that $a \times b$ is equal to $b \times a$, is it possible to enter into any other realm of mathematics than that of the complex variable.

When I reported these criticisms to Gibbs, his comment was that all depends on what your object is in making those sacrosanct rules for operating upon symbols. If the object is to interpret physical phenomena and if we find we can do better by having a rule that $a \times b$ is equal not to $b \times a$ but to *minus* $b \times a$, as in the multiplication of two vectors, then, he said, the criticisms of the Germans are beside the point.

The fact is that Gibbs, though a great mathematician, was not primarily interested in mathematics as such. His interest lay in its applications to reality—in the substance rather than the form. All his contributions to pure mathematics were sought and found not as mere proliferations of formal and abstract logic but as by-products of his work in interpreting the facts of the physical universe.

The far-reaching effects of Gibbs's work apply not only to inorganic physics and chemistry but also to the organic world. One of the most elaborate reviews of Gibbs and his relation to modern science is by Lieutenant Colonel Fielding H. Garrison, M.D., assistant to the librarian of the Army Medical Library, Washington, D. C., in which he shows, among other things, the application of Gibbs's work to the equilibrium of heterogeneous substances in general physiology.

Despite Gibbs's retiring disposition and his disinclination for general society he was most cordial in his personal contact with colleagues and students and never seemed to lack time to give to any

one who chose to discuss the subject in which he was so deeply interested. He made on all a deep impression of kindliness. I well remember the remark of Percey Smith, now professor of mathematics at Yale, who was a fellow student of Gibbs with me, as we walked out of one of Gibbs's lectures, "What a *gentle* man he is!"

He enjoyed a joke, often laughed and excited laughter. He took pleasure in applying his mathematics in simple ways. One of his minor but fascinating papers before the Yale Mathematical Club was on the "Paces of a Horse," the writing of which was doubtless suggested by watching a horse which he had just purchased. Probably no one else ever put a horse through his paces as scientifically or amusingly as Gibbs did in that paper.

Gibbs himself never contributed to the social sciences. Apparently I am the only one of his pupils who, after first doing some teaching in mathematics and physics, became professedly an economist, although Professor E. B. Wilson, Gibbs's chief interpreter as to mathematics, has taken a lively interest in many lines of social science and statistics and was this year president of the American Statistical Association.

After several years' graduate study, partly in mathematics under Gibbs and partly in economics under Sumner, the time came for me to write my doctor's thesis and I selected as my subject, "Mathematical Investigations in the Theory of Value and Prices." Professor Gibbs showed a lively interest in this youthful work, and was especially interested in the fact that I had used geometric constructions and methods including his own vector notation.

The late Professor Allyn Young, of Harvard, also made occasional use of vectors in his economic work. Another economic student and writer, a brilliant young Norwegian, Professor Ragnar Frisch, has latterly used the vector notation and says he could scarcely think without it. Professor Frisch will this year be visiting professor at Yale from the University of Oslo.

It is one of the handicaps of mathematics in the social sciences that there are so few who are trained in both lines for such study, and this particularly applies to any applications of Professor Gibbs's vector analysis. If vector analysis should become more widely understood and used by students in the social sciences, doubtless it would be more generally utilized, at least as a vehicle for thought.

Occasionally, and increasingly, the ideas and notations of the differential and integral calculus are applied by mathematical economists and statisticians. But, of course, most of the mathematics employed in the social sciences consists of simple algebra. There is a saying which, by the way, was quoted by Gibbs in his address on "Multiple Algebra" that "the human mind has never invented a labor-saving machine equal to algebra."

There are several fairly distinct branches of social science to which mathematics has been, or may be, applied. The chief of these may be distinguished as (1) pure economics, (2) the "smoothing" of statistical series, (3) correlation and (4) probabilities, all of which overlap to some extent.

My own chief interest in social science, from a mathematical point of view, has been in the first of these four groups, pure theory.

When I began my work in this field in 1891, mathematics in economic theory was looked at askance, despite the fact that many years before, as early as 1838, Cournot had written his brilliant "Researches into the Mathematical Principles of the Theory of Wealth." This book later greatly stimulated Professor Edgeworth, of Oxford, and Professor Marshall, of Cambridge, and to-day is ranked among the economic classics. The same may be said of Jevons's "Theory of Political Economy" pub-

lished in 1871. But in 1891, when my own economic studies began, even the work of Cournot was almost unknown to economists, and that of Jevons was little used. If one will turn the pages of the main economic literature of 1891 and earlier, he will find practically no formulas and no diagrams. But Walras and Pareto in Switzerland and Pantaleoni and Barone in Italy, Edgeworth and Marshall in England, Westergaard and Wicksell in Scandinavia and a few other students in other countries were using and defending the new method.

When, at the request of Professor Edgeworth, I read a slightly mathematical paper on the "Mechanics of Bimetalism" before the Economic Section of the British Association for the Advancement of Science at Oxford in September, 1893, I well remember how, in the discussion of that and other mathematical papers, Professor Edgeworth was, as he expressed it, "damped" by the unfriendly criticism of these new methods by Professor Sidgwick and others.

But little by little, the usefulness of mathematics has come to be appreciated. Besides the older writers already mentioned and Auspitz and Lieben, whose work on price determination of 1889 was one of my first inspirations, there have gradually come into this field many younger writers among whom may be mentioned Professor Henry L. Moore, of Columbia University, Professor J. H. Rogers, of the University of Missouri, Professor C. F. Roos, of Cornell University, Professor Griffith C. Evans, of Rice Institute, Professor Henry Schultz, of the University of Chicago, Professor Harold Hotelling, of Stanford University, W. A. Shewhart, of the Bell Telephone Laboratories, Professors J. Maynard Keynes, A. C. Pigou and Arthur L. Bowley, of England, Professors Albert Aftalion and Jacques Rueff, of France, Ladislaus von Bortkiewicz, of Berlin, Dr. Otto Kühne, of Germany, Professor Wl. Zawadski, of Poland, Professor E. Slutsky, of Russia, Professor Gustav Cassel, of Sweden, Professor Ragnar Frisch, of Norway, Dr. Willem L. Valk, of Holland, Professors Corrado Gini and Luigi Amoroso in Italy.

And besides the fact of such accessions to the ranks of the small band of professed mathematical economists is the even more significant fact that economists in general have not only ceased decrying mathematics but are, in many cases, making some slight use of it themselves.

The late Professor Marshall, of Cambridge University, was one of the first to perceive what was happening. He said:

> A great change in the manner of thought has been brought about during the present generation by the general adoption of semi-mathematical language for expressing the relation between small increments of a commodity on the one hand, and on the other hand small increments in the aggregate price that will be paid for it, and by formally describing these small increments of price as measuring corresponding small increments of pleasure. The former, and by far the more important, step was taken by Cournot;[2] the latter by Dupuit[3] and by Gossen.[4] But their work was forgotten; part of it was done over again, developed and published almost simultaneously by Jevons and by Carl Menger in 1871, and by Walras a little later. Jevons almost at once arrested public attention by his brilliant lucidity and interesting style.
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> . . .
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> A training in mathematics is helpful by giving command over a marvelously terse and exact language for expressing clearly some general relations and some short processes of economic reasoning, which can indeed be expressed in ordinary language, but not with equal sharpness of outline. And, what is of far greater importance, experience in handling physical problems by mathematical methods gives a grasp, that can not be obtained equally well in any other way, of the mutual interaction of economic changes. The direct application of mathematical reasoning to the discovery of economic truths has recently rendered great services in the hands of master mathematicians to the study of statistical averages and probabilities and in measuring the degree of consilience between correlated statistical tables.

[2] "Recherches sur les principes mathématiques de la théorie des richesses," 1838.

[3] "De la mésure d'utilité des travaux publics" in the Annales des Ponts et Chaussées, 1844.

[4] "Entwickelung der Gesetze des menschlichen Verkehrs," 1854.

Mathematics serves economic theory in supplying such fundamental concepts based on the differential calculus and also through the process of differentiation solves problems of maxima and minima, as in the simple process of determining formally what is the price that the traffic will bear in order to make profits a maximum.

The chief realm of economic theory to which mathematical analysis of this kind applies is that of supply and demand, the determination of prices, the theoretical effect of taxes or tariffs on prices. The results can not always be reduced to figures but are often useful in terms of mere inequalities.

For instance, among the chief theorems shown mathematically by Cournot are the following: That a tax on a monopolized article will always raise its price, but sometimes by more and sometimes by less than the tax itself; that a tax on an article under unlimited competition always raises its price but by an amount less than the tax itself; that a tax proportional to the net income of a producer will not affect the price of his product; that fixed charges among costs of production do not affect price nor do taxes on fixed charges; that opening up free trade in a competitive article between two previously independent markets may decrease the total product.

Among the most surprising paradoxes discovered by the mathematical method is one shown by Edgeworth, that if a monopolist sells two articles, say first and third class railway tickets, for which the demand is correlated, it may be possible to tax the third class tickets, at a fixed amount each, with the result that the monopolist not only pays the tax but lowers the prices of both kinds of tickets.

Familiarity with mathematics will save many confusions of thought. For instance, it is just as important in economics to distinguish between a high price and a rising price as it is in physics to distinguish between velocity and acceleration. Rate of price change has important effects, both theoretically and in practice, on the rate of interest and on the volume of business.

Theoretically the rate of interest ought to be higher during a period of rising prices, or depreciation of the dollar, by an amount equal to the rate of depreciation, and it ought to be lower during appreciation.

Practically, however, the rate of interest is slow of adjustment and, what is more important, inadequate in adjustment. A mathematical statistical analysis of this slowness and inadequacy helps explain great business upheavals as shown in my new book on "The Theory of Interest." I may say here, parenthetically, though the case is somewhat different, that the recent crash in the stock market was, in large measure, the price paid for tardiness in raising the rate of interest which should have risen over a year ago but was held down artificially.

Again, mathematics will save the economic student and the student of accounting from the many confusions of double counting, especially in the intricate theory of income.

Another elementary, but important, use of mathematics in economics is in making sure that a problem is determinate by counting and matching the number of independent equations and the number of unknown quantities. A great deal of unnecessary misunderstanding has existed and still exists in economic science as to what determines the rate of interest or other magnitudes in economics. These misunderstandings would not exist if the contestants would take the trouble to express themselves mathematically. If we view the matter mathematically it soon becomes evident that one contestant has seen only one of the determining factors, and the other another, without either of them realizing that both are compatible and needed in a complete economic equilibrium. The concept of economic equilibrium in which many factors act and react on each other

is one of the chief elementary contributions of mathematics to economic theory, and one stressed by Cournot, Walras, Marshall, Pareto and Edgeworth.

Still another use of mathematics is in illustrating geometrically or analytically the fact that a price, or a "marginal utility," is a function not simply of one but of many variables, the function being purely empirical and incapable of analytical or arithmetical expression. In fact, the economic world is a world of n dimensions.

Thus the marginal utility of bread to John Doe is a function of his quantity not only of bread consumed, but of butter, sugar and numerous other variables.

I have myself tried to apply these and other mathematical ideas to the formal solution of the problem of prices of commodities, the rate of interest, the relation of capital to income, the purchasing power of money and what Simon Newcomb, the astronomer-economist, called the equation of societary circulation, now called the equation of exchange (the volume of circulating medium multiplied by its velocity of circulation is equal to the price level multiplied by the volume of trade per unit of time).

Most of these and other applications of mathematics to economic theory consist in short chains of reasoning. Professor Marshall had the impression that only short chains of reasoning could ever be expected in mathematical economics. He said:

> It is obvious that there is no room in economics for long trains of deductive reasoning: no economist, not even Ricardo, attempted them. It may indeed appear at first sight that the contrary is suggested by the frequent use of mathematical formulae in economic studies. But on investigation it will be found that this suggestion is illusory, except perhaps when a pure mathematician uses economic hypotheses for the purpose of mathematical diversions, for then his concern is to show the potentialities of mathematical methods on the supposition that material appropriate to their use had been supplied by economic study. He takes no technical responsibility for the material and is often unaware how inadequate the material is to bear the strains of his powerful machinery.

But as time goes on, there appear instances of somewhat longer trains of reasoning.

I may take an example from my own work. I have tried to show how it is possible to estimate numerically through suitable mathematical equations the velocity of the circulation of money. The formula for this was derived through a chain of mathematical reasoning requiring several links and embracing a considerable number of variables of which the chief are the volume of money in circulation, the annual flow of money into and out of banks and the annual cash payments to labor. This problem, by the way, of evaluating the velocity of circulation of money had been pronounced insoluble, and without mathematical analysis it might well be so considered. Incidentally, the calculations indicate that money in the United States circulates about twenty-five times a year. In other words, the average dollar stays in the same pocket about two weeks.

To turn to a different example, both Professor Ragnar Frisch and myself, by independent methods, both of them highly mathematical, have shown how, theoretically, under certain simple hypotheses, to accomplish the statistical measurement of "marginal utility" or desirability as a function of one's income. This would determine whether or not it is true that if one man has double the income of another his tax ought to be double, more than double or less than double in order that he should make the same sacrifice. In other words, it would supply a mathematical criterion by which to judge the justice of a progressive income tax.

I say "would" rather than "does" simply because as yet the statistics available do not seem adequate for any accurate evaluation. But Professor Frisch and I are both hoping to pursue this

study further. His and my preliminary results are not inconsistent. My own formula is derived by a chain of mathematical reasoning which results in expressing the ratio of the "marginal utility" of money for a person with a certain income to the "marginal utility" which he would have with a different income in terms of the following elements: those two incomes, the percentages which would be spent on food, rent, etc., under the two respective incomes and the index numbers of prices of food, rent, etc., relatively to another country, serving as a standard of comparison.

Mathematics also helps make clear the "dimensionality" of the magnitudes treated. Thus, the quantity of wheat, its price and its value are three magnitudes as unlike in dimensionality as time, velocity and distance. The rate of interest has the simplest dimensionality, being, like angular velocity, of dimension t^{-1}.

Mathematics helps us analyze time relationships in general, especially to avoid the old confusion between capital and income, the one relating to an instant of time, the other to a period of time.

Capital-income analysis is a development of the last two score years, but its roots go back generations. Every good treatise on algebra includes the formulas for capitalizing annuities and bonds, the formulas underlying the bond tables used in every broker's office.

While the development of mathematical economics from the theoretical side has been steady and impressive since I was a young man, it has by no means been so rapid as the development of the other three branches to which I have referred.

"Smoothing" statistical data, the fitting of formulas and curves to statistics, has, of course, been one of the aims of statisticians for many generations. In this way we have derived our mortality tables, the basis used by actuaries for calculating life insurance premiums.

I understand that the second J. Willard Gibbs lecture was by Robert Henderson on "Life Insurance as a Social Science and as a Mathematical Problem." The importance of this branch of our subject does not need to be emphasized in an insurance center like Des Moines.

Actuarial science is, of course, a development of the formulas for capitalization or discount, particularly as applied to annuities, combined with the introduction of the probability element based on mortality statistics. It is essentially an analysis of interest and risk. It could be, and perhaps some day will be, applied to other economic problems besides life insurance, as soon as statistics are adequate for assessing risk numerically in other realms than human mortality. In fact, one of the crying needs of economic science is a reliable basis for evaluating risks.

Concurrently with actuarial science has developed a science of mathematics of mortality in relation to population, extending at least back to the days of William Farr, superintendent of the statistical department of the registrar general's office of England half a century ago. To-day this science has been further developed by Knibbs, of Australia, Lotka and Glover in the United States, and others.

Recently with the development of statistics of industry the art of curve fitting by mathematical methods has grown very rapidly, and examples of it will be found in many current issues of statistical journals. I am, myself, with a collaborator, Max Sasuly, working on a new method of curve fitting aimed to avoid the use of any preconceived formula but letting the statistical data themselves write their own formula, so to speak.

One important phase of curve fitting which links it closely with the study of economic theory is the statistical evaluation of supply and demand curves. Among those who have worked in this

field are Professor Henry L. Moore, of Columbia University, Professor Henry Schultz, of Chicago University, Dr. Mordecai Ezekiel, of the U. S. Department of Agriculture, Professor G. F. Warren, F. A. Pearson and C. F. Roos, of Cornell University, and Professor Holbrook Working, of Stanford University. Professor Schultz was apparently the first to work out the statistical determination of the effect of the tariff on the price of an imported commodity—sugar.

The third group of mathematical work in the social sciences, the development of correlation, is closely associated with the name of Karl Pearson, of the University of London, who is still living. His correlation coefficient has become almost a standard procedure in economic statistics as well as in other sciences, including biology, in which he is primarily engaged. To-day many, if not most, economists, especially if they work in statistics, are making some use of such correlation coefficients. Through them they have been forced to adopt mathematical aids in spite of old traditions and prejudices.

Professor Warren M. Persons, formerly of Harvard, has worked out correlations with lag showing the interrelations of various economic phenomena in such a way as to serve the purposes of forecasting business conditions. A more elaborate method of correlation has been worked out by Karl Karsten, of New Haven, a private statistician, who has made tables of correlation between every pair of available series of economic statistics and has put these together by multiple correlation so as to predict any one of the series from all the others which are found to serve toward that end. He is now issuing regularly a forecast of commodity prices, of the volume of business, of stock market trends and of various other economic factors.

In the study of the so-called business cycle and forecasting future fluctuations, mathematical economists and statisticians have made increasing use of what is virtually differentiation or integration. Thus I have emphasized "price-change" as distinct from price, of which it is the differential quotient. Reciprocally, Mr. Karsten has applied the idea of "quadrature" to the relations of two statistical series where one is virtually derivable from the other by integration. This means if the curves are cyclical that they are related as are the curves of sines and cosines so that one curve is at zero while the other is at a maximum or minimum.

One development in this field in which I have been especially interested has been the study of the distribution of the lag. This appears to be a skew distribution, but nearly normal if time is plotted on a logarithmic scale.

As already indicated, risk is one of the fundamental elements in the mathematical analysis of actuarial science. It is also, in a different way, through frequency distribution, a fundamental element in correlation analysis. In fact, there have been more or less successful attempts by Karl Pearson to resolve a mortality curve into a sum of several frequency curves and by Arne Fisher to do the reverse—synthesize a set of frequency curves representing mortality from certain causes into the total mortality curve. It may also be pointed out that our second topic, curve fitting and smoothing, whether by least square methods or otherwise, is largely a study in probability.

All this brings us to the fourth chief branch of our subject, the mathematical analysis of probability in general in so far as this relates to social phenomena as embodied in statistics. This has been increasingly studied by many economists, especially the late F. Y. Edgeworth, editor of the *Economic Journal*. Also

mathematical statisticians such as G. Udny Yule, Arthur Bowley, R. A. Fisher, Sir William Beveridge, Truman L. Kelley, A. C. Whitaker, William L. Crum, Thiele and others have done much constructive work in this field.

Professor Vilfredo Pareto tried to work out a formula for statistics of incomes in relation to the number of persons possessing incomes of various sizes, and the Pareto curve has become quite famous. It has been shown, however, particularly by Professor Macaulay, of the National Bureau of Economic Research, that the Pareto curve is nothing but the "tail" of a probability curve, although Pareto himself had been loath to admit this. It is true that this particular sort of probability or distribution curve is not "normal" even if the abscissas are plotted on a logarithmic scale. It often happens in statistical series, especially where the frequency distribution lies between zero as one extreme and infinity as the other, that the frequency or probability curve while very skew on the arithmetical scale turns out to be nearly "normal" on the logarithmic scale.

I have, of course, by no means exhausted the list of applications of mathematics to economics, still less to the other social sciences. Many applications have been made which are not easily classified under the four heads I have noted, namely, pure theory, curve fitting, correlation and probabilities.

Of these other and miscellaneous applications, the most important, at least in the field of economics and statistics, seems to be that of index numbers. The theory and practice of index numbers have had a special fascination for many of us because they occupy a tantalizing position on the borderline between *a priori* rational theory and empirical makeshift and because of the many pitfalls encountered in their study. It is closely related to the subject of probability. In my book on "The Making of Index Numbers," I have tried to find the best formula for an index number out of several score available formulas.

It is also true, of course, that the last three divisions of our subject, curve fitting, correlation study and probability, traverse all fields of knowledge. They apply not only to my own branch of the social sciences, economics, but to all others such as sociology, anthropology and education, as well as to fields outside of social science such as psychology, biology, hygiene and eugenics. In all these we find a development of mathematical method. Each has its own special concepts, measures and principles, such as the cranial index of anthropology, the intelligence quotient of psychology and education, the Mendelian principle in heredity, and these the mathematician may study in terms of averages, index numbers, correlations, deviations, frequency distributions and otherwise. Just as the multiplication table is applicable in more than one field of knowledge, so mathematics in general is peculiar to none. Sooner or later every true science tends to become mathematical. The social sciences are simply a little later to be reached than astronomy, physics and chemistry, while the biological sciences are later still.

Scientific method is one and the same, whether employed in such sciences as Gibbs developed, or in others. Mathematics is, as Gibbs said, simply a "language." It is required for the best expression of scientific method when the relations to be expressed become sufficiently involved to require it in preference to ordinary language which is less precise and complete. The outlook is bright for a healthy development of mathematics in the social sciences.

LUNAR TEMPERATURES

By Dr. EDISON PETTIT and Dr. SETH B. NICHOLSON
CARNEGIE INSTITUTION OF WASHINGTON, MOUNT WILSON OBSERVATORY

OUR knowledge of the temperature of a celestial object must come through its radiation, which has suffered losses by filtration through its own and the earth's atmosphere and in the observing instruments. In the cases of the moon, the planet Mercury and to a great extent Mars, the first of these absorptions is negligible, and the problem of determining their surface temperatures is simpler than for the other planets.

The term radiation as used here means collectively ultra-violet, visual and infra-red light, the only distinguishing physical feature between these divisions being their wave-lengths. The unit of wave-length in common use is the micron (μ), which is one thousandth of a millimeter or ten thousand angstroms. Ultra-violet light consists of all wave-lengths less than 0.4 μ; visual light, that between 0.4 μ and 0.76 μ, and infra-red light, all wave-lengths greater than 0.76 μ. The unit of intensity is one calory per square centimeter per minute, written 1 cal cm^{-2} min^{-1}.

The radiation from a planet consists of reflected solar radiation, which is practically confined to the wave-lengths between 0.3 μ and 5 μ, and low temperature radiation from its warmed surface, called planetary heat, which reaches us principally through the great transmission band in the atmospheric water-vapor between 8 and 14 μ. With the exception of cosmic radiation below the X-ray region no celestial radiation to the violet of wave-length 0.2897 μ, or to the red of 15 μ has been detected, although the latter wave-length is still somewhat uncertain. The shaded curve in Fig. 1 shows the atmospheric transmission for radiation from a celestial object in the zenith on Mount Wilson. From this figure it can be seen that the reflected radiation between 0.3 μ and 5 μ is transmitted by a glass plate 0.165 mm thick (microscope cover-glass) while most of the planetary heat is not transmitted by it. Hence this thin glass becomes a means of separating the two kinds of radiation from a planet.

The general scheme which we have used for determining planetary temperatures consists in the following steps. (1) Measure with the vacuum thermocouple on an arbitrary scale the whole radiation (reflected light plus planetary heat) from a small area of the planet, and that transmitted by the cover-glass (practically all the reflected light and a nearly negligible amount of planetary heat). (2) Calibrate these measures by the radiation from a star which we have already standardized. (3) Separate the planetary heat from the reflected light by subtracting the radiation transmitted by the cover-glass from the total radiation received and apply small corrections necessary because of the slight absorption of reflected light and the slight transmission of planetary heat. (4) Compare the planetary heat so determined with that which computation shows would be obtained with our instruments from a black body at various temperatures outside our atmosphere.

In making the observations a vacuum thermocouple with a window made of rock salt is mounted at the focus of a reflecting telescope. The two junctions of the thermocouple, which are only two or three millimeters apart, are made by fusing two small wires of bismuth to the ends of another which is an alloy of 95 per cent. bismuth and 5 per cent. tin.

These are connected electrically to a D'Arsonval galvanometer in such a manner that the currents which are produced when the individual junctions are heated separately flow in opposite directions. When both junctions are heated simultaneously no deflection occurs, hence the thermocouple is compensated against general radiation from the sky and surrounding objects. In the case of the moon the image was so large that it would heat both junctions and it was necessary to shield all the thermocouple except one junction, hence the compensation was only partial, but since the required sensitivity was low this caused no inconvenience.

Small thin metal plates $\frac{1}{2}$ to 1 mm square are fused over the junctions of the thermocouple wires and covered with a mixture of lamp-black and platinum-black on their exposed surfaces. These black plates absorb within about 2 per cent. all the radiation from celestial objects and convert it into heat which, for the small changes of temperature obtained in practice, produces a thermo-electric current proportional to the intensity of the radiation received, irrespective of its wave-length. There is a current popular idea that thermocouples measure "radiant heat" or infra-red light, but radiation instruments such as the thermocouple, bolometer and radiometer when made with black receivers are perfectly color-blind and do not distinguish the various wave-lengths, measuring ultra-violet, visual and infra-red radiation with equal facility.

Of the radiation which is measured from the red variable star χ Cygni at minimum more than 99 per cent. is infra-red light; from the star Sirius 80 per cent. is visual and ultra-violet light, while from the sun 56 per cent. is visual and ultra-violet and 44 per cent. infra-red radiation. The radiation from the star Betelgeuse when focused on the receiver of a thermocouple by the 100-inch reflector raises its temperature fifteen thousandths of a degree, and the star Boss 4342, which is eight magnitudes fainter radiometrically, raises the temperature of the receiver only nine millionths of a degree Centigrade. These small temperature changes produce currents of the order of one and a half ten millionths of an ampere and 9×10^{-11} amperes, respectively.

The measurements could be calibrated in the fundamental way by comparing the observed deflections with those obtained from a standard radiator at a known distance. For example, the Hefner lamp at sea-level, without a diaphragm, emits 0.00156 calories per minute on each square centimeter (156×10^{-5} cal cm^{-2} min^{-1}) at a distance of one meter. This is an inconvenient process when the thermocouple is attached to the telescope, and so we have calibrated the radiation from certain stars and use them as standards.

To facilitate computation we have established a scale of magnitudes for stellar radiation called "radiometric magnitude" which agrees with the visual magnitude scale for the blue stars, type Ao. The radiometric magnitude of a star, therefore, is the visual magnitude of an Ao star which would give the same galvanometer deflection when both are observed with a reflecting telescope. From direct comparisons of stars with the sun, a Hefner lamp and a condensed filament electric light, we find that the energy which reaches us from a star of zero radiometric magnitude in the zenith on Mount Wilson is 17.3×10^{-12} cal cm^{-2} min^{-1}, and from this the energy which we receive from any star of known radiometric magnitude may be determined.

Table I is a list of stars in order of their radiometric magnitude (column 3) which have been used as standards. The last two columns of this table give the energy, E, which reaches the thermocouple, and E′, that which reaches the

solar system, expressed in both cases in cal $\times 10^{-12}$ cm^{-2} min^{-1}. The difference between these two columns is the energy absorbed in the earth's atmosphere and in the telescope.

TABLE I

Star	Sp. Type	Rad. Mag.	Vis. Mag.	E	E′
Betelgeuse	M2	−1.67	0.92	81	132
Antares	M1	−1.32	1.22	58	96
Sirius	A2	−1.27	−1.58	56	145
Arcturus	Ko	−0.98	0.24	43	64
Aldebaran	K5	−0.60	1.06	30	46
Capella	Go	−0.38	0.21	25	36
Vega	A1	0.10	0.14	16	44
Procyon	F3	0.22	0.48	14	22
Rigel	B8	0.23	0.34	14	50
Pollux	G9	0.53	1.21	11	20
α Ceti	M2	0.72	2.82	8.9	14
Altair	A2	0.74	0.89	8.8	23
Spica	B3	1.00	1.21	7.4	48
α Arietis	K1	1.24	2.23	5.5	8
Regulus	B9	1.47	1.34	4.5	14

The image of a star is always smaller than a receiver of the thermocouple, so that the deflections produced by it are independent of the size of the receiver, but when the moon or a planet is observed the deflections depend on the size of the receiver if it is smaller than the image of the observed object. It is, therefore, necessary to reduce the planetary observations to a receiver of definite size, and one square second of arc, in the telescope field, has been adopted for that standard.

The part of the total deflection which is due to planetary heat is determined by taking the difference between it and the deflection with the thin glass in the optical beam. The latter must be corrected for the losses by reflection from its two surfaces, the absorption of the glass and its transmission of a small amount of planetary heat. In the case of the moon these corrections amount to about 3 per cent. of the observed lunar radiation.

In computing the temperature corresponding to the observed planetary heat the assumption is made that the planet under observation radiates like a black body. In the case of the moon less than one eighth of the incident solar radiation is reflected, and this low reflecting power indicates an approach to the condition of a black body. The assumption is further justified by the observation that when a plate of fluorite is used as an absorbing screen the planetary heat absorbed by it has the same ratio to that transmitted as would be expected from a black body at that temperature.

The amount of energy radiated per unit of surface from a black body varies as the fourth power of its absolute temperature, and the amount of radiation of each wave-length is known for each temperature from Planck's formula. It is possible, therefore, to compute the amount of radiation which would reach our instruments from an area which subtends an angle of one square second of arc of a black body at various temperatures, making allowance for the losses in our atmosphere and in the telescope. The computed values of planetary heat for various temperatures are given in Table II. By entering this

TABLE II

T (K) Absolute	T (C) Centigrade	E	m'_r	$\Delta m'_r$
100°	−173°	0.00018	+12.47	−0.49
200	− 73	0.140	+ 5.23	−0.28
300	+ 27	1.36	+ 2.76	−0.20
400	+127	5.73	+ 1.45	−0.18
500	+227	10.0	+ 0.60	−0.18
600	+327	17.5	− 0.01	−0.17
700	+427	26.4	− 0.46	−0.17
800	+527	37.8	− 0.85	−0.16

table with the quantity of radiation observed for any point on the moon or planet its temperature may be obtained. Here T (K) is the absolute temperature of the planetary surface in degrees

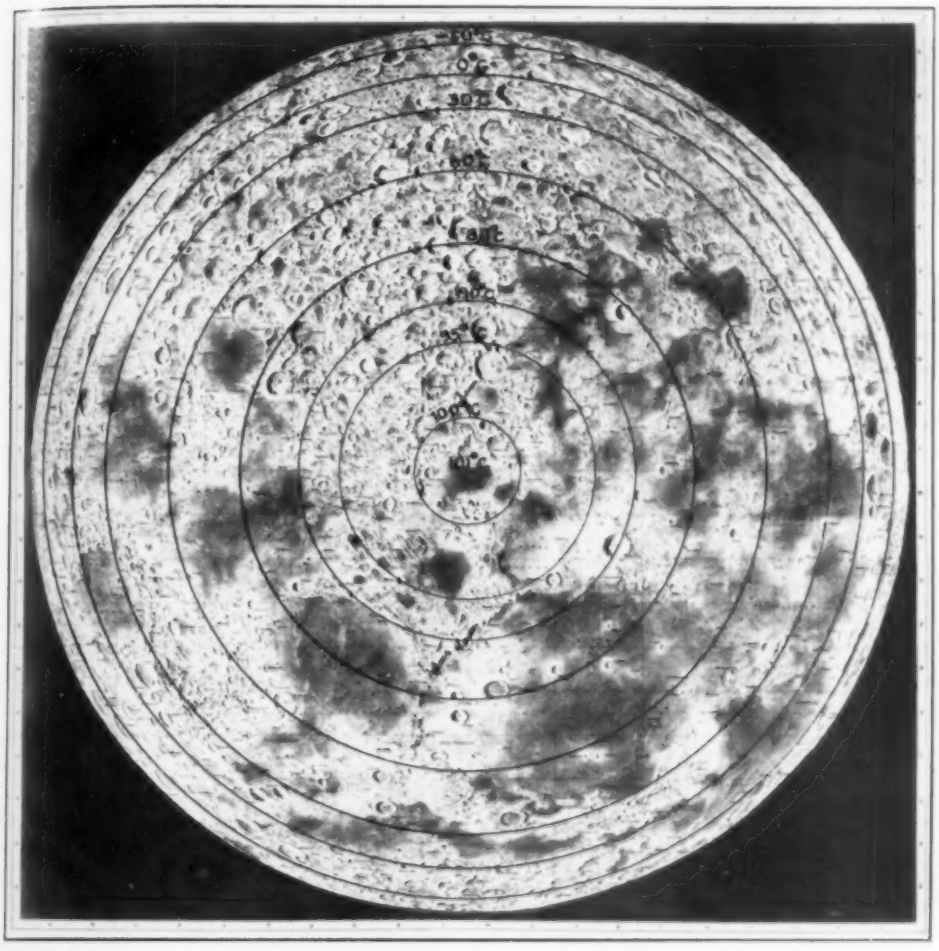


PLATE I. ISOTHERMAL LINES ON THE MOON

Centigrade; T (C) is the corresponding temperature Centigrade; E is the planetary heat eliminated by the microscope cover-glass, in a solid angle of one square second of arc, expressed in units of 10^{-12} calories per square centimeter per minute; m'_r is the radiometric magnitude corresponding to this energy, and $\Delta m'_r$ is a small correction obtained from the theoretical lunar temperature as described later.

From observations extending over a period since 1923 we find that the temperature deduced for the point on the moon where the sun is directly overhead is 135° C. when measured at full moon, but only 82° C. when measured at quarter phase. The difference in these results is evidently due to the fact that the rough surface increases the radiation toward the lunar zenith but diminishes that toward the horizon, and the actual temperature from the radiation measurements lies between these figures.

To determine the actual temperature the distribution of planetary heat and light about the subsolar point was determined by measurements made from night to night as the subsolar point passed over the earthward face of the

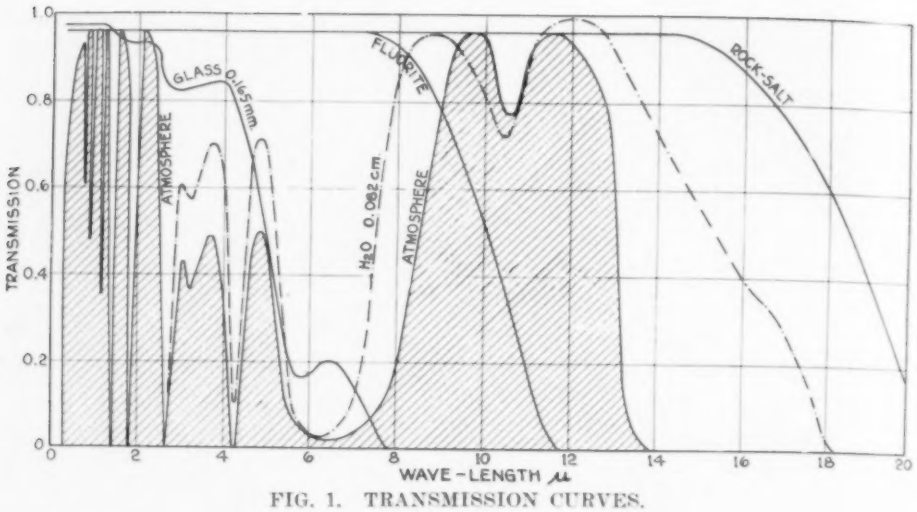


FIG. 1. TRANSMISSION CURVES.

moon between first and last quarter. The curves for both light and planetary heat are given in Fig. 2. The mean radiation in all directions from the sub-solar point was 1.93 cal cm^{-2} min^{-1}, which is equivalent to a temperature of 118° C.

The temperature of the subsolar point may be computed from the solar constant (1.95 cal cm^{-2} min^{-1}) after deducting the solar radiation reflected by the surface of the moon and that conducted into its interior. From the distribution of reflected light shown in Fig. 2 we find that 0.24 cal cm^{-2} min^{-1} is reflected into space, and from measurements of the rate of cooling during an eclipse of the moon we find that less than 0.1 cal cm^{-2} min^{-1} is conducted into the moon, showing that it is a very poor conductor. Therefore the solar radiation effective in warming the lunar surface and that which must be radiated from it is 1.61 cal cm^{-2} min^{-1}, which is equivalent to a temperature of 101° C. The temperatherefore, 17° C. in excess of that theoture obtained from direct measures is, retically possible from a consideration of the quantity of solar radiation available to heat the moon.

Of the various explanations of this discrepancy which have been considered, an error in the values of the atmospheric transmissions seems to be the most probable, owing to the difficulty of determining the transmission constants of the atmosphere for radiation with wavelengths between 8 and 14 microns. An increase of 19 per cent. in the atmospheric transmissions used in reducing the direct measures would decrease the resulting temperature 17° C., and accordingly we have computed corrections to the atmospheric absorption for various temperatures based on that assumption. These corrections are given in Table II as $\Delta m'_r$. When these corrections are used in obtaining temperatures of other planets or other regions on the moon the results may be considered as having been obtained by a comparison of the measured radiation with that from the subsolar point on the moon, assigning to it the temperature deduced from the amount of incident solar radiation corrected for losses which have been determined by direct observation with the thermocouple. The effect of these corrections is to lower the measured temperatures of Mercury about 45° C., Venus 9°, Mars 10° and the moon 17°.

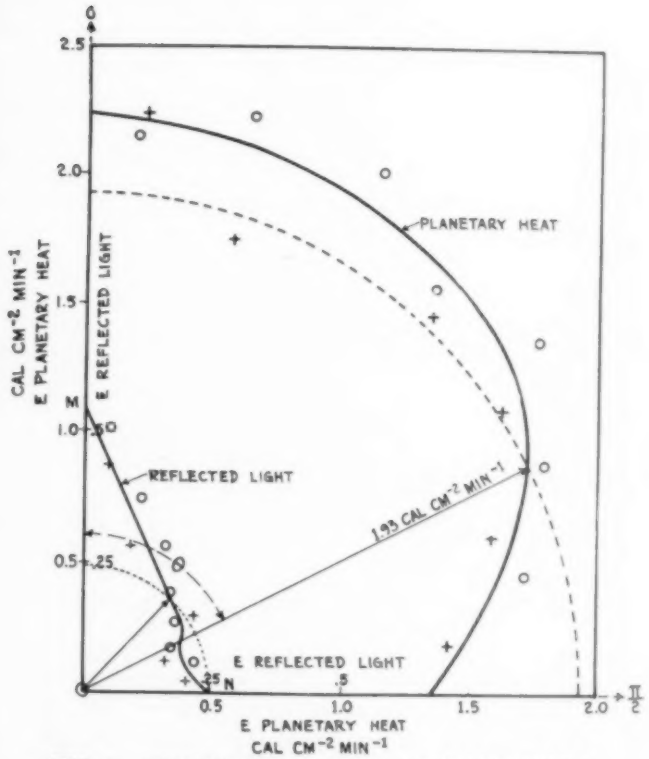


FIG. 2. DISTRIBUTION OF PLANETARY HEAT AND REFLECTED SUNLIGHT ABOUT THE SUBSOLAR POINT ON THE MOON.

Measurements made on the dark side of the moon gave – 153° C. for its temperature. This is so low that considerable observing will be necessary to determine it accurately, for the lower limit of temperature which we can detect is a little less than – 173° C.

The variation of radiation and temperature over the sunlit side of the moon was obtained by allowing the image of the full moon to transit the thermocouple while a moving photographic plate traced the resulting galvanometer deflections called drift curves. Drift curves in a north and south direction were obtained by driving the thermocouple with a motor. The planetary heat was found to vary from a practically unmeasurable quantity at the limb to a maximum value at the center approximately as cosine$^{3/2}\theta$, where θ is the angular distance on the moon from the subsolar point. Plate I is a plot of the isothermal lines, upon a relief map of the moon, in degrees Centigrade computed from this data. They represent mean values and do not distinguish between the light and dark areas. The maria are, in general, somewhat warmer than the mountainous regions, but the difference is only a few degrees.

The diurnal march of temperature for a point near the equator on the moon determined from the above data is shown by the line labeled "Moon, Equator" in Fig. 3. From this and what has been said above it is seen that

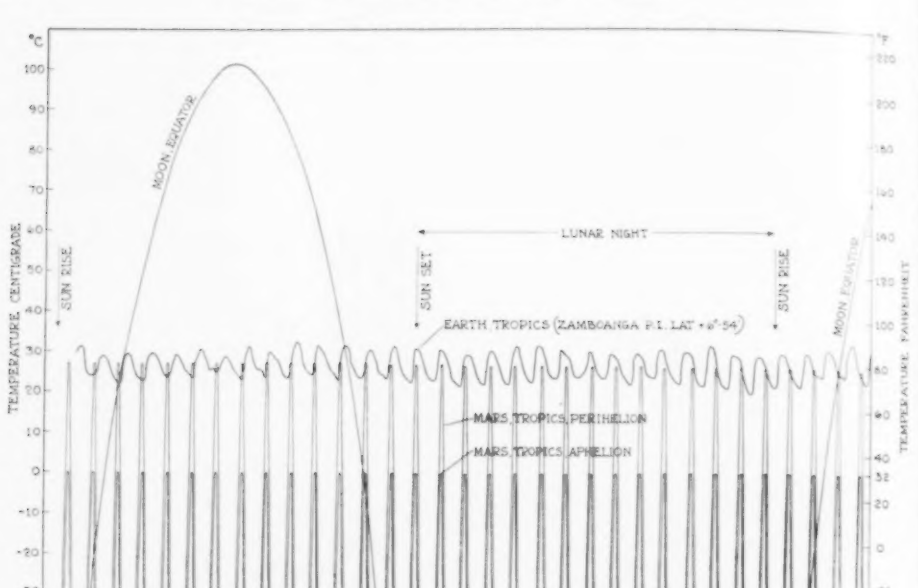


FIG. 3. DIURNAL VARIATION IN TEMPERATURE ON THE EARTH, MOON AND MARS COMPARED.

the temperature rises from that of liquid air at sunrise to the boiling-point of water at lunar noon, returns as the sun becomes lower in the lunar sky and hovers near that of liquid air during the next fortnight. The line labeled "Earth, Tropics" is the diurnal variation in temperature for a point near the earth's equator, Zamboanga, Philippine Islands (lat. 6° 54′ N). The contrast in temperature range is very striking. The graph for Mars was obtained from drift curves on the planet which we took at the oppositions of 1924 and 1926, and they were reduced in the same manner as those for the moon described here. The curve shows that the maximum temperature comes near noon and that the fall in temperature is very large as the sun approaches the Martian horizon, indicating a very dry atmosphere. An interesting feature of this curve is the large range of 27° C. in the noon temperature between perihelion and aphelion calculated from the eccentricity of the planet's orbit. In the case of the earth this effect would amount to only one degree and would be masked by other climatic variables.

The changes in temperature which take place during a lunar eclipse were investigated at the eclipse of June 14, 1927. A point near the south limb of the moon was chosen for continuous measurement since this point passed only 11′ north of the center of the umbra of the earth's shadow. For this point the duration of the eclipse was $2^h\ 40^m$, the partial phases being 1^h each. The temperature T, the energy E_R received from the sun and E emitted by the moon during the eclipse are shown diagrammatically in Fig. 4. For the point measured, the temperature fell from 342° K = 69° C. to 175° K = −98° C. during the first partial phase, continued to drop to 156° K = −117° C. during totality and rose again abruptly

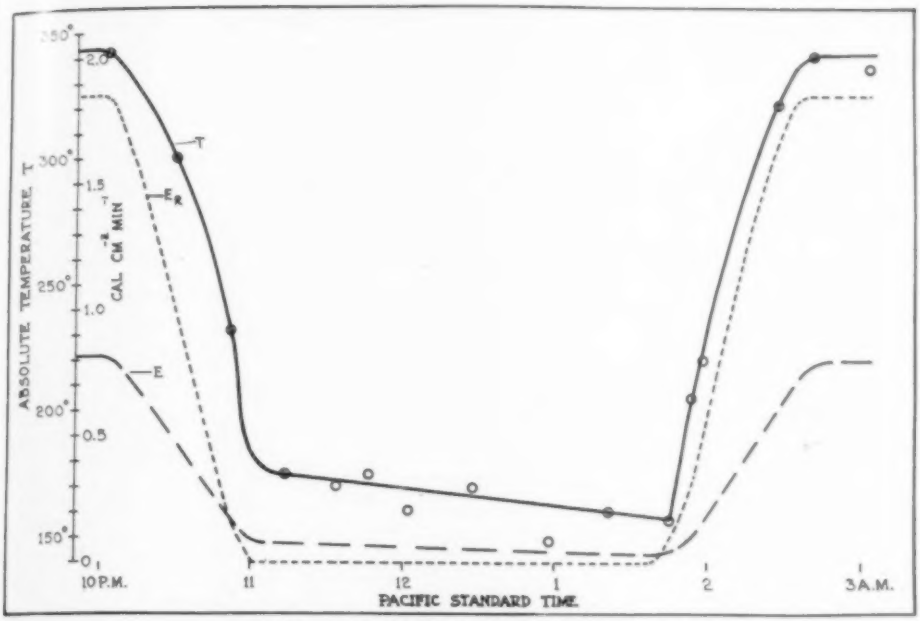


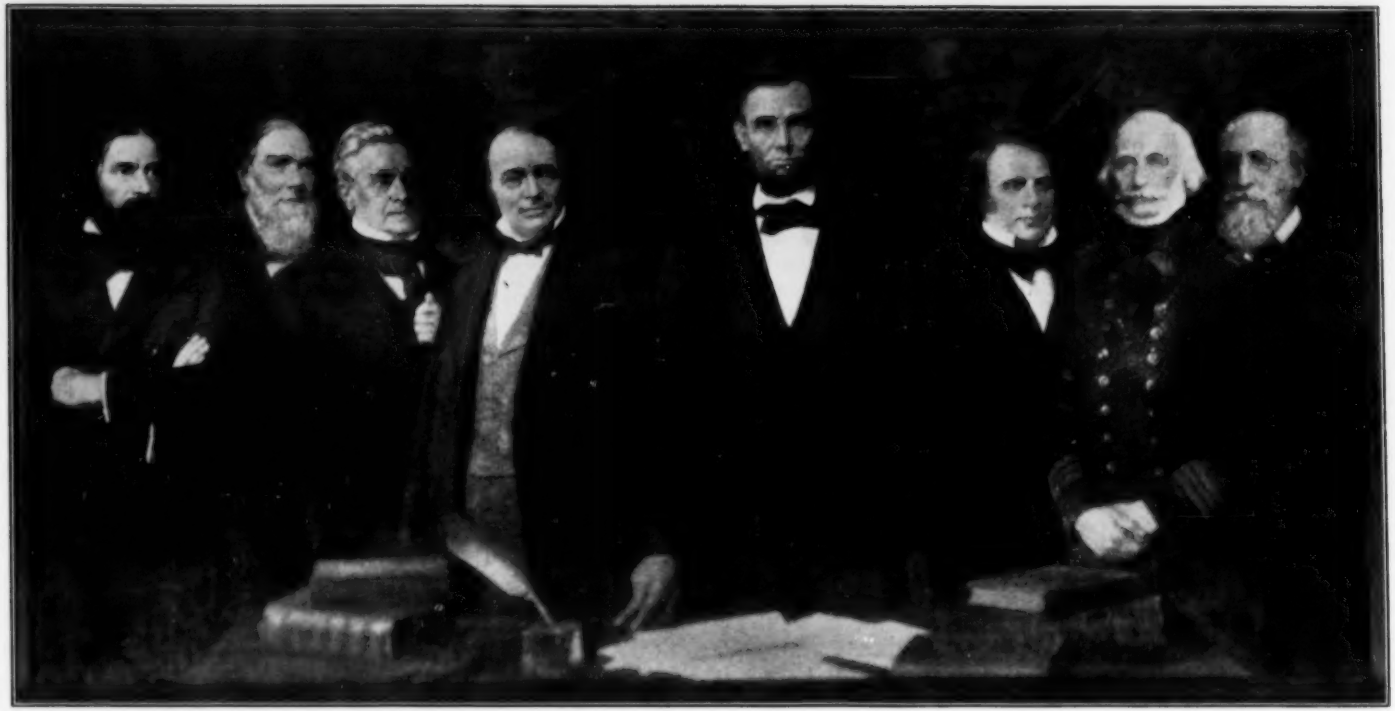
FIG. 4. LUNAR TEMPERATURE

ENERGY RECEIVED AND ENERGY EMITTED BY THE MOON DURING A LUNAR ECLIPSE.

to nearly the original temperature during the last partial phase. The deflections even toward the end of totality were between 2 and 3 mm and could be measured with precision by the methods which we used.

From this curve it can be shown that the heat conductivity of the lunar crust is very low, probably on account of its porous or granular nature, and only about 0.1 cal cm^{-2} min^{-1} (5 per cent.) of the energy received at the subsolar point is transmitted into the interior of the moon.

The enormous change in temperature of 186° C. observed in this lunar eclipse, the greater part of which took place during the partial phase, is in strong contrast to the fall of 2.8° C. observed at the solar eclipse of June 8, 1918, by the Washburn College party at Matheson, Colorado, where the duration of the partial phase was nearly the same. This serves to illustrate the governing effect of an atmosphere on planetary temperatures, since in this illustration the only physical distinction between the two circumstances was the presence of an atmosphere at the solar eclipse observed from the earth. It is chiefly the presence of water-vapor as a constituent of the earth's atmosphere which gives it this property, and the large diurnal variation in the temperature of Mars shown in Fig. 3 indicates a lack of this constituent in its atmosphere.



FOUNDERS OF THE NATIONAL ACADEMY OF SCIENCES

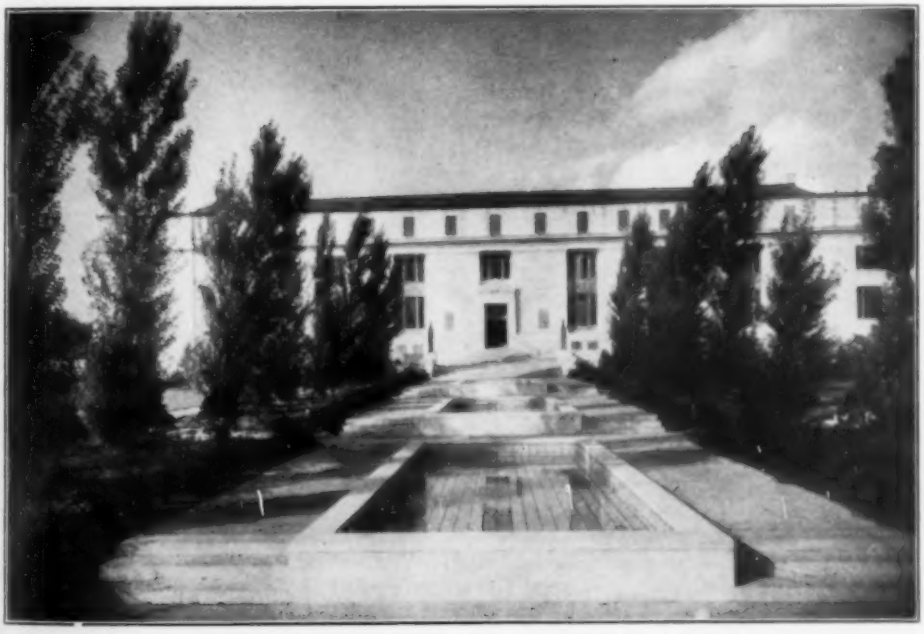
A PHOTOGRAPH OF THE PAINTING BY ALBERT HERTER IN THE BOARD ROOM OF THE ACADEMY BUILDING. THE NAMES, READING FROM LEFT TO RIGHT, ARE: BENJAMIN PEIRCE, ALEXANDER DALLAS BACHE, JOSEPH HENRY, LOUIS AGASSIZ, ABRAHAM LINCOLN, SENATOR HENRY WILSON, ADMIRAL CHARLES H. DAVIS, BENJAMIN APTHORP GOULD. THE PICTURE WAS PLANNED BY DR. GEORGE ELLERY HALE. IT IS A GROUP OF MEN WHO WERE IN WASHINGTON ABOUT THE YEAR 1863 AND WHO CONSULTED AMONG THEMSELVES REGARDING THE FORMATION OF AN ACADEMY TO ADVISE THE GOVERNMENT IN SCIENTIFIC MATTERS. THE BILL IN CONGRESS WAS SPONSORED BY SENATOR WILSON.

THE PROGRESS OF SCIENCE

THE SPRING MEETING OF THE NATIONAL ACADEMY OF SCIENCES

THE National Academy held its annual meeting in Washington during the last week in April; at the same time there met in the national capital many other societies, groups and committees concerned with scientific work. The charter of the academy, approved by Abraham Lincoln on March 3, 1863, when the country was in the midst of civil war, requires the academy to "investigate, examine, experiment and report upon any subject of science or art," whenever called upon by any department of the government. This duty of the academy has in large measure been taken over by the scientific bureaus of the government since organized, but when war became imminent in 1916 there was established at the request of Woodrow Wilson the National Research Council under the Congressional charter of the National Academy. After performing useful services during the war the council was continued as an agency of the academy. The academy and the council occupy jointly a beautiful marble building near the Lincoln Memorial, completed six years ago at a cost of one and a half million dollars as the last work of the distinguished architect, Bertram Grosvenor Goodhue.

When the National Academy was chartered the number of members was limited to fifty, but this restriction was removed by the Congress in 1870. According to its present rules fifteen new members may be elected each year, the total membership having been limited to 250 until this year when the upper limit was made 300. The Royal Society elects



THE BUILDING OF THE NATIONAL ACADEMY OF SCIENCES AND THE NATIONAL RESEARCH COUNCIL

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WM. W. COBLENTZ, PH.D. (CORNELL '03)
PHYSICIST, BUREAU OF STANDARDS.

fifteen members and maintains a membership of about 400. The National Academy is thus smaller than the Royal Society but larger than the Paris Academy and other continental academies. As there are now some 20,000 men engaged in scientific work in the United States the selection of fifteen of these is a high distinction. Photographs are presented of those elected with the exception of Dr. J. W. Alexander, professor of mathematics, Princeton University, and Dr. Eugene T. Allen, research chemist, Geophysical Laboratory, Carnegie Institution of Washington.

The distribution of the members of the academy among the different states and institutions gives a measure of interest in research and appreciation of the work of leaders in science. It will be noted that of the fifteen new members three are connected with the California Institute of Technology at Pasadena. There were already at the institute six members, including Dr. T. H. Morgan, the president of the academy, and Dr. R. A. Millikan, the foreign secretary. The Mount Wilson Observatory of the Carnegie Institution at Pasadena has no fewer than seven members, so there are fifteen members in these two institutions which did not exist a few years ago. Both are due to Dr. George Ellery Hale and represent a most remarkable achievement in the organization and advancement of scientific research. The University of California, with the Lick Observatory, has on its faculty fourteen members of the academy, and there are nine members at Stanford. California, until recently lacking in scientific men of high distinction, now ranks with Massachusetts and New York and is far in advance of any other state. There are only five members in Pennsylvania and two in Ohio.

There are thirty-eight members of the academy connected with Harvard University, and its retention of scientific leadership is as remarkable as the de-

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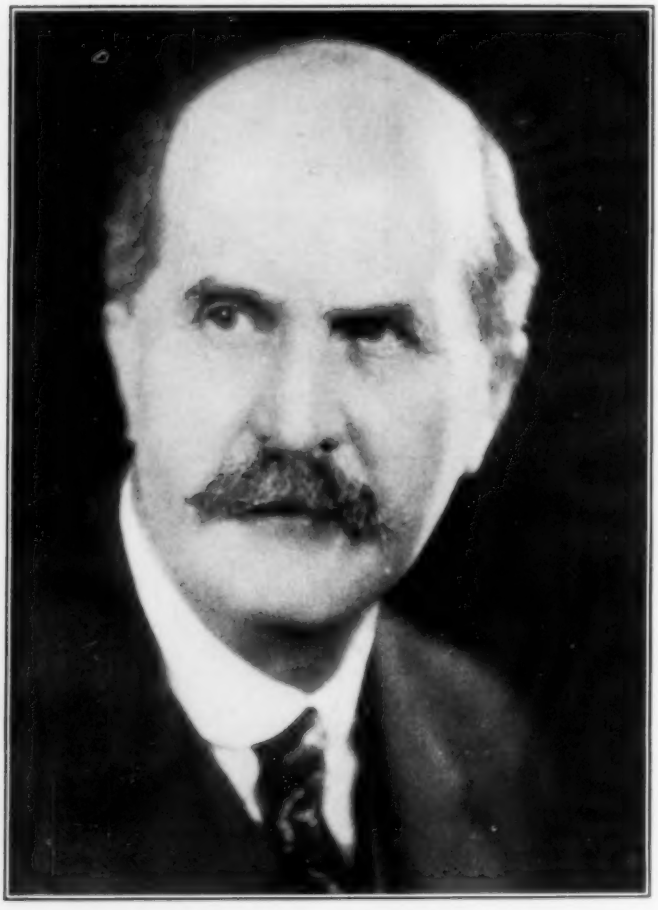
BERTHOLD LAUFER, PH.D. (LEIPZIG '97)
CURATOR OF ANTHROPOLOGY, FIELD MUSEUM OF NATURAL HISTORY, CHICAGO.

velopment in California. An examination of the distribution among the different departments shows that in every science Harvard stands first or nearly first. There are seventeen members of the academy at Chicago, sixteen at Yale, thirteen at the Johns Hopkins, twelve at Columbia and ten at Princeton. Among the state universities Wisconsin

K. S. LASHLEY, PH.D. (HOPKINS '14)
PROFESSOR OF PSYCHOLOGY, UNIVERSITY OF CHICAGO.

has eight and Illinois five. There are distinguished scientific men in the government institutions and surveys at Washington, but relatively fewer than formerly. A recent notable development has been, on the one hand, the establishment of research institutions, particularly the Carnegie Institution of Washington and the Rockefeller Institute for Medical Research, and, on the other hand, the carrying out of research work in industrial laboratories, more especially by the General Electric Company and the American Telephone and Telegraph Company.



SIR WILLIAM BRAGG

THE AWARD OF THE FRANKLIN MEDAL TO SIR WILLIAM BRAGG AND DR. JOHN F. STEVENS

In 1913 Mr. Samuel Insull, of Chicago, gave to the Franklin Institute a certain sum for the founding of the Franklin Medal to be awarded from time to time in recognition of the total contributions of individuals to science or to the applications of physical science to industry. The medal is of gold, having on one side a medallion of Benjamin Franklin done from the Thomas Sully portrait, the original of which is in the possession of the institute.

This year two medals were awarded—one to Dr. John F. Stevens in recognition of his unifying solutions of widely varying and difficult engineering problems met in the planning of the great Panama Canal, of the marked power shown by him in the organization of the engineering forces which later built that canal and of his eminent success in the location, construction and administration of railroads in this country and in foreign lands; the other to Sir William Bragg in recognition of a life work in the study of X-rays and radioactivity in the course of which he made fundamental contributions to that realm of

DR. JOHN F. STEVENS

physics, of his development of a method of determining molecular and crystal structure by the reflection of X-rays and of his fruitful guidance of the Davy-Faraday Research Laboratory and of the Royal Institution of Great Britain.

Dr. Stevens was born at West Gardiner, Maine, in 1853. His first engineering experience was with a firm of engineers in Lewiston, but he was soon drawn to the West. From 1874 to almost the present time he has been associated with many American railroads, among which may be mentioned the Denver and Rio Grande; the Chicago, Milwaukee and St. Paul; the Canadian Pacific; the Great Northern, and the New York, New Haven and Hartford. His list of honors from governments is a long one, including the Distinguished Service Medal of the United States. He is an officer of the Legion of Honor of France. In 1925 he was awarded the John Fritz Medal, the highest honor American engineers can pay to one of their number.

A few of his splendid achievements are as follows. Early in 1889 he entered the service of the Great Northern Railway and was assigned the task of locating its line over the Rocky Mountains. This he did when he discovered the

Marios Pass, which has the lowest grades in the northern United States and is the straightest route from the head waters of the Mississippi to Portland and Puget Sound.

In 1905 Dr. Stevens was called by our government to take charge of the work of constructing the Panama Canal. He spent eighteen months in the Canal Zone as chief engineer; he brought order out of chaos, planned all the details of construction and organization and started the vast machine going with a contented and healthy army of 30,000 men.

Sir William Bragg was born at Wigton, England, in 1862. His collegiate education was obtained at Trinity College, Cambridge. In 1886 he was appointed professor of mathematics and physics in the University of Adelaide, Australia, and while there began his investigations in the field of radioactivity. In 1909 he was appointed Cavendish professor at Leeds University. In 1915 he became Quain professor of physics at the University of London, where he remained until his election in 1923 to his present position as director of the Royal Institution of Great Britain, Fullerian professor of chemistry at the Royal Institution and director of the Davy-Faraday Research Laboratory. He is a fellow and a Rumford medalist of the Royal Society. In 1915 he received the Nobel Prize for physics, which distinction he shared with his son, Professor W. Lawrence Bragg.

Sir William's extensive and valuable studies have been in the modern and important fields of radioactivity, X-rays and crystal structure, in fact, they are of such a fundamental nature that his name is a household word to all students in the exact sciences.

In radioactivity his experiments on the determination of the ranges of the alpha particles from various radioactive substances threw much light on the mechanics of ionization in gases and on the laws of absorption of these rays by matter.

In the field of X-rays and crystal structure he showed that the cleavage faces of a crystal reflect X-rays according to the same laws that apply in ordinary optical reflection, and he derived the formula known as the Bragg equation for space lattices. Using this equation and with observations made on numerous crystals by means of an X-ray spectrometer of his own design he determined the various distances between the atomic planes in these crystals and the nature of the atoms in these planes. In this way he put crystallography on an exact and measurable foundation.

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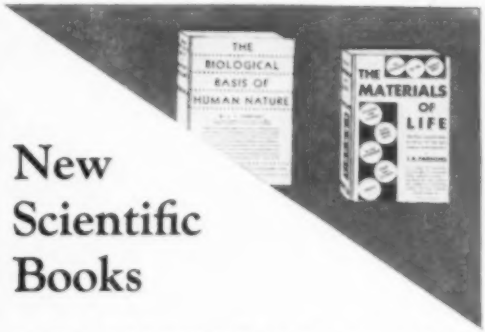
Correspondence should be addressed to the secretary, Jaques Cattell, The Science Press Printing Company, Lancaster, Pa.



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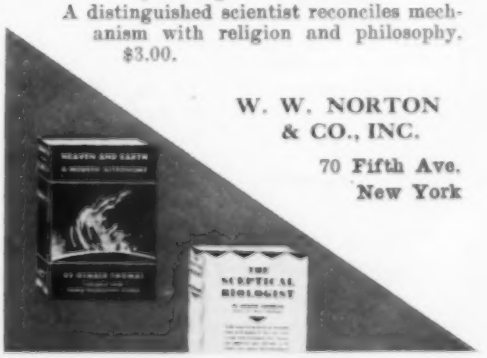

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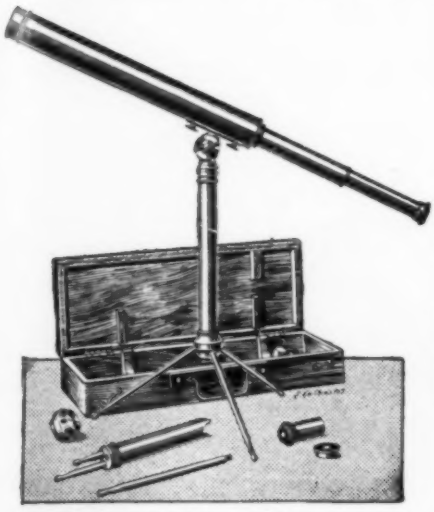

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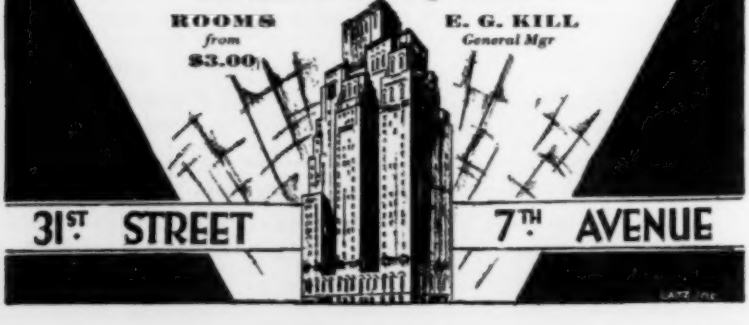

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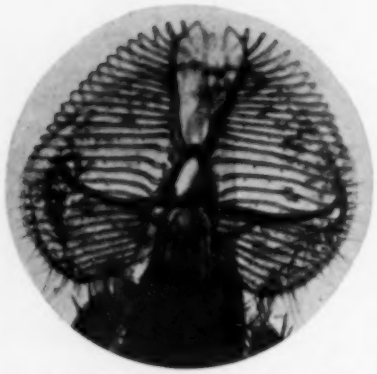

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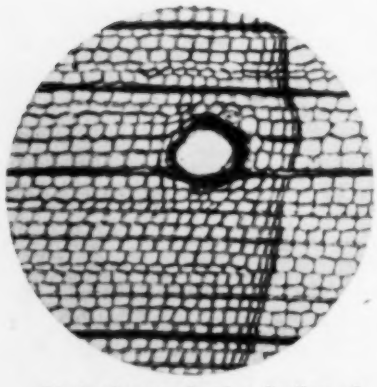

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